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AOSTRA

USSR EXCHANGE TOUR REPORT

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Alberta

OIL SANDS TECHNOLOGY
AND RESEARCH AUTHORITY

The Alberta Oil Sands Technology and Research Authority (AOSTRA) is pleased to issue this report, *Observations and results of the recovery of bitumen and heavy oil by enhanced oil recovery (EOR) methods in the USSR.*

In accordance with the long term agreement between the Government of the USSR and the Government of Canada to facilitate economic, industrial, and scientific-technical cooperation, and wishing to promote the development of scientific and technical cooperation in the area of recovery and utilization of tar sands and heavy oil, AOSTRA embarked on an exchange tour with the USSR. During the period August 6 to October 28, 1989, James R. Yurko and Vladimir M. Reitman were guests of the "Interbranch Scientific Technological Complex, Oil Recovery" Institute (MNTK), and visited various field projects, factories, mines and institutes in the USSR. This report contains information that was garnered from the tour and is the first step in a formal agreement between AOSTRA and MNTK to exchange specialists to tour each others secondary and tertiary recovery facilities and to discuss areas where further exchange of technology and personnel may be possible, and the potential for future business ventures.

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Executive Director
Technical Programs & International Activities

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Observations And Results Of The Recovery Of Bitumen And Heavy Oil By Enhanced Oil Recovery (EOR) Methods In The USSR

(USSR Exchange Tour — August 6 To October 28, 1989)

By
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The information within this report was gathered from various published sources, AOSTRA's library, field visits, and that supplied by our hosts (MNTK) in the U.S.S.R.

The opinions and observations are those of the author J.R. Yurko except for those prepared by V.M. Reitman concerning the theoretical and experimental works. Translations were done by Mr. V.M. Reitman and completion of the report was a coordinated effort between the principals involved.

I would like to thank the office staff in Edmonton (Patty Hunt, Diane Teppan and Rachel Recto) for their diligent work in preparing diagrams, typing and editing this report.

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CONTENTS

Executive Summary 1

Oil Production in the U.S.S.R. 4

Current Trends for Oil in the U.S.S.R. 4

Bitumen 11

Moscow 15

Ukhta - Yarega 23

Okha (Sakhalin Island) 29

Bugulma - Tataria (Melekess) 32

Kiev 40

Krasnodar 41

Alma Ata (Kazakhstan) 46

Baku (Azerbaijan) 49

Research 54

Contacted Specialists 58

References 64

Appendix 1 65

Appendix 2 109

Appendix 3 123

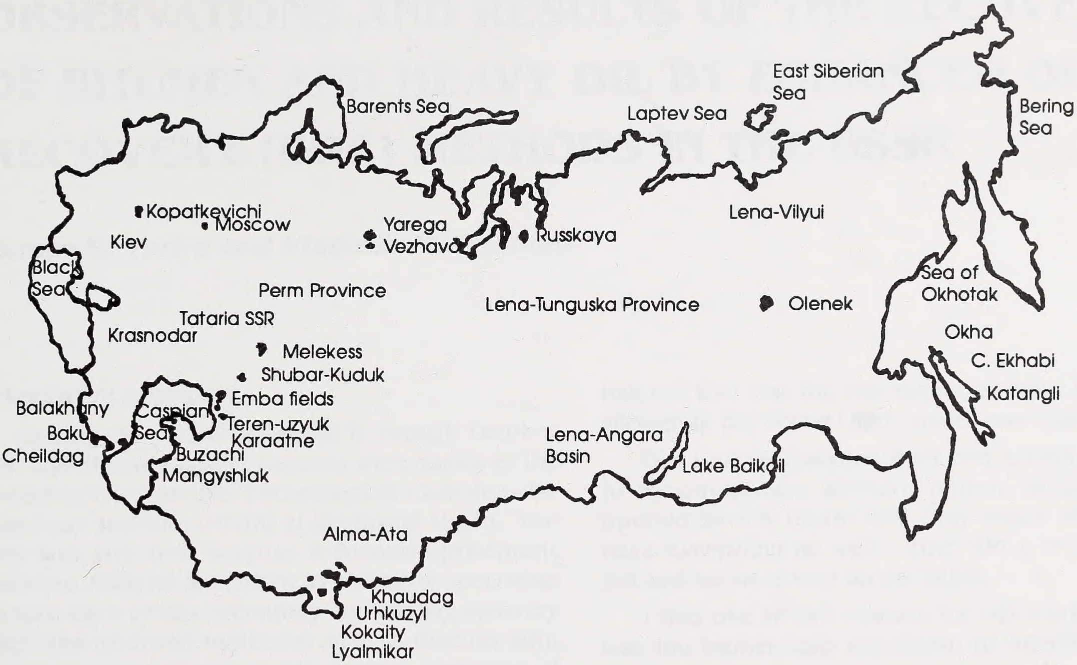
Appendix 4 133

Appendix 5 137

Appendix 6 171

Appendix 7 183

Appendix 8 195



Itinerary

Moscow
Ukhta(Yarega)
Okha
Bugulma (Melekess)
Kiev
Krasnodar
Alma-Ata
Baku (Balakhany)

OBSERVATIONS AND RESULTS OF THE RECOVERY OF BITUMEN AND HEAVY OIL BY ENHANCED OIL RECOVERY (EOR) METHODS IN THE USSR

James R. Yurko and Vladimir M. Reitman

EXECUTIVE SUMMARY

During the period of August 6 through October 28, myself and Vladimir Reitman were guests of the "Interbranch Scientific Technological Complex, Oil Recovery" Institute (MNTK) in the Soviet Union. The trip was the first step in a formal agreement between AOSTRA and MNTK to exchange specialists to tour each others secondary and tertiary recovery facilities (thermal methods) and to discuss with each other possible areas for further exchange of technology, personnel and possibly future business ventures.

The program, which was put together by the Soviets, was truly awesome. We were taken to heavy oil and bitumen fields in all areas of the Soviet Union, as well as visiting and talking to engineers and geologists of numerous institutes both affiliated with MNTK and not.

During our stay we travelled 37,100 km by air and over 1,300 km on surface within the Soviet Union. Needless to say, the variety of stops was very interesting, however, the travelling took its toll toward the end of the trip, in simple exhaustion.

Total travel during the period was about 57,000 km, which I am sure will represent the largest accumulation of travel over a three month period that we will ever do in a lifetime.

The organization, by the Soviets was excellent. We were met at all destinations by representatives who had our accommodations and schedules set. The hospitality and social programs were well planned and they were also very cooperative in allowing us free time for ourselves. We feel the job done by our host was monumental. We were told that our tour was the first comprehensive tour ever allowed in the Soviet Union under one Visa.

Our tour represented their first efforts in trying to accommodate Western people in the newly opened Soviet Union and they really wanted to have everything go well. They did a tremendous job and we were very appreciative.

I feel one of the reasons for our trip's success was the tremendous reputation of AOSTRA within the scientific community involved in thermal recovery methods. The hospitality shown by AOSTRA during the UNITAR Conference in Edmonton was remembered and as quoted by many people, "AOSTRA is the world leader in thermal recovery methods" and as the Soviet Union now wants to open up to the West, AOSTRA is who they want to have a working relationship with.

The itinerary included visits to:

A) Uktha - Yarega - Komi Province

- Toured the Yarega Underground Mine.
- Discussed surface thermal methods on fields at Yarega and USA.
- Toured surface facilities.
- Toured a BU 53/300 drill rig (largest in U.S.S.R.) presently drilling at 5 km.

B) Okha - Sakhalin Island

- This is a restricted area, and we were the first North Americans to tour their fields.
- Toured heavy oil and bitumen fields around

Okha, viewed asphalt lakes. Reviewed successful thermal methods used on the Okha field.

- Toured the offshore jack up drilling rig Sakhalinskaya, the largest in their offshore fleet.
- Small fields, minimal production, Okha is a successful layered steam soak-waterflood project.

C) Bugulma - Tartaria

- Toured numerous small heavy oil and bitumen fields in Tartaria, reviewed their work in C.S.S., and fireflood projects.
- Talked with Institute people about the geology of Tartaria.
- Examined and reviewed numerous outcrop and surface working of oil sands, and refinery dating back to 1870.

D) Kiev - Ukraine

- Had talks with Institute people concerning thermal methods in the Ukraine, however, there are very few fields which have heavy oil and bitumen, therefore, most of our talks were generally about oil and gas in Canada.
- Discussed with some experts our pipeline system in Canada, and to some extent the regulations and safety measures which govern the construction of pipelines in Canada. (What we knew about it.) They are very interested in learning about our regulatory process for pipeline construction, as well as our safety procedures. Because of two major pipeline explosions in the U.S.S.R., a new committee is responsible for drafting new guidelines. Some of these people will visit Alberta late in 1989 or early 1990 and may contact AOSTRA for help and information.

E) Krasnodar - Southern Russian - Black Sea Area

- Toured several oil oil fields in the Krasnodar region. Most are medium to heavy crude fields that are now using steam injection to improve falling production.
- The highlight was visiting MNTK "NEFTEOTDACHA" where we saw their gas-steam generator. They toured us through their factory which builds the units and also took us to some field tests. These units were very impressive, with the largest unit able to inject 10 tonnes of steam per hour into a well. The units are completely self contained and portable.

  These people would like to demonstrate their unit in Canada, and I suggested bringing it to the oil show. They were very excited and would appreciate an invitation. They have shown the unit in the U.S.S.R. and Hungary.
- Again this group very much wants to participate in joint ventures with Western entities, to produce all kinds of products (i.e. insulated pipe, packers, steam-gas generators, etc.). They also want to develop technological exchanges. This group was very impressive, in that they went ahead on their own and developed the generator without the financial backing of the Central Government. Many institutes are envious of this group because of their initiative and success. These people would be well worth talking to in the future, for further exchanges and possible joint ventures.

F) Alma-Ata - Kazakhstan

- We discussed the geology of heavy oil and bitumen deposits in Kazakhstan. Essentially they are now in the process of doing a five year geological evaluation of new and old deposits to determine viable deposits for development. They have many small deposits which are directly amenable to AOSTRA technology.
- We were also guests of the Kazakhstan Minister of Highways, who discussed their use of "Kiree" a bitumen and sand mixture used to make roads. This process has been very successful and they see it as a future staple of their industry. They have recently signed a huge contract to build roads in Mongolia and anticipate using "Kiree" a lot.
- Kazakhastan is a very rich A.S.S.R. and their institutes want to participate in a joint venture very badly with a Western entity. Again the reputation of AOSTRA was well known, and further exchanges and relations are welcomed.

G) Baku - Azerbaijan

- We toured several oil fields (light oil) on the Apsheron Peninsula as well as observing offshore drilling and production platforms in the Caspian Sea. We also toured a huge modern factory which constructs the offshore drilling platforms, this was really interesting because we saw that Soviets can produce and build modern efficient factories, however, they need Western equipment to do it.
- Of particular interest was the surface deposits of Kir, bitumen and the asphalt lakes. The Apsheron Peninsula is covered by numerous surface deposits of bitumen as well as millions of tonnes of oil in surface soils, lakes, offshore slugs, etc. We discussed the Taciuk Process with them and they seemed very interested. We described how the Taciuk Process could help clean the surface mess, and also process their bitumen deposits. Eventually the Soviets are going to have to clean up the enormous surface oil contamination, and with environmental concerns now becoming a big issue with the government, the Taciuk Process would combine to improve the environment as well as processing their bitumen into saleable products.
- We had an audience with Dr. Abasov, a member of the Academy of Science and also a member of Parliament. He is also the top oil official in Azerbaijan and one of the top in the U.S.S.R. He was particularly interested in the Taciuk Process and other work being done by AOSTRA.
- We also toured the site of the Balakhany underground mine test site. This site was developed by the Yarega people to build an underground mine drainage facility similar to Yarega. However, difficulties with gas, but mostly shaft drilling problems led to the cancellation of the project. They feel that if they could get modern shaft drilling technology from the West, they might restart the development of the project. They are interested in AOSTRA experience in developing UTF.

H) Moscow

- The headquarters for our visit was Moscow where MNTK's head office is situated.
- We discussed our trip with their officials, both the good and the bad, and also discussed AOSTRA and the set up of the oil and gas industry in Alberta. They were very interested because we said that 85% of the oil and gas is owned by the government and our system is set up on development by private companies with royalties paid to the government. Development was done by the private companies and thus tremendous competition was developed within the industry to produce as efficiently as possible and to generate the best possible returns. They talked about how their centrally controlled government system doesn't develop competition and thus new ideas and techniques are very hard to get implemented.

  They were also very interested in the role of the ERCB and how different government departments affect the overall development of oil and gas in Alberta.

  MNTK is a newly created organization within the Soviet Union (1986).

  They are one of twenty-two organizations (Institutes) within the total energy sector of the soviet union.

  Their mandate is:

  1) Increase the efficiency of existing deposits (waterflood technology).
  2) The creation of new efficient methods to increase production.
  3) Update technology and build equipment for more efficient oil recovery.
  4) Technology Licensing Organization responsible for selling and licensing their technology to the world.

  As I mentioned earlier, they feel AOSTRA is the world leader in research and technology of secondary and tertiary recovery methods. Therefore, in following their mandate they want to develop a meaningful working relationship with AOSTRA and also other Alberta agencies or companies who would be interested in Joint Ventures within the U.S.S.R.

General Observations and Comments

- The Soviet engineers and scientists realize that they have to catch up with the West in technology. They also realized that the overall production of oil in the U.S.S.R. has peaked and that the giant fields of Western Siberia have started to decline; with no more giants available for production, they will have to develop more costly smaller fields and they will have to develop more efficient production through secondary and tertiary methods.

- Soviet theoretical work is very close to ours, however, when it comes to practical application and even pilot plants they are seriously lacking. Their biggest problem is equipment, reliable equipment, with reliable back up for repairs and modification. Therefore, they want to participate in joint ventures with Western firms to produce oil to sell on the world market, to get **hard currency**, to buy Western equipment.
- The Ruble being worthless outside Comecon, they have no money to buy Western equipment thus they can't build reliable test facilities and thus test their technologies. It is a real Catch 22. Now that Moscow has opened up and are encouraging development with the West, Soviet organizations are trying very hard to acquire Western equipment, technology and expertise.
- There is one huge problem, they have **No Money** and they have to find scenarios for generating **Hard Currency**.
- I feel that AOSTRA and the Government of Alberta along with Alberta companies should continue to keep up and promote new contacts within the U.S.S.R., because if their problems are solved and their markets open up it will be a great opportunity to those first in. In fact Alberta companies like "Fracmaster" and "Lavalin" have already signed Joint Venture Agreements with the U.S.S.R., with the Fracmaster joint venture being of particular interest to AOSTRA.
- MNTK officials asked that the exchange trip for their experts be set up as soon as possible i.e. next spring. They want to keep up the momentum generated by our trip to the U.S.S.R. (their quote) and need **positive results** as soon as possible to **present to their ministry**.
- The AOSTRA posters signifying the projects of AOSTRA were a tremendous success. In many cases they proved to be the "ice breaker" during our initial discussion with various institutes. They were very popular with all professional people in all the areas we visited.

OIL PRODUCTION IN THE U.S.S.R.

Oil production in the U.S.S.R. dates back many centuries when oil and bitumen was gathered by hand from seeps and mud volcanoes. Production has increased tremendously such that the Soviet Union is now the worlds largest producer of oil (≈1.63 million tonnes/day).

Slow growth occurred until the mid 1940's, however, after WWII the significance of oil was realized and it became the most important driving fuel of the modern Soviet economy. After WWII, tremendous growth in Soviet oil production occurred, with the discovery of large reserves in Tataria (Romashkino), Kazakhstan and the super huge discoveries in Western Siberia (Samatlor) (Figure 1).

During the period between 1945 to 1975, the Soviet Oil Ministry was concerned only with primary (waterflood) production and exploration for light and medium crude, however, around 1970 it recognized that the growth rate in petroleum production (Figure 2) was rapidly declining and new supergiant and giant fields were not being found to add significantly to their reserves. The fields in Tataria, Azerbaijan, Ukraine and Western Siberia were reaching maturity or were in decline, and more expensive oil had to be found to replace this production. Along with more expensive Arctic exploration, and development of smaller, higher cost fields, enhanced recovery methods were considered as a viable alternative, along with the development of heavy oil and bitumen.

CURRENT TRENDS FOR OIL IN THE U.S.S.R.

The following tables and graphs illustrate very well, the problems facing the oil sector in the future. Declining production, higher costs, remote drilling, fill in drilling and high water cuts indicate that a total commitment to E.O.R. and heavy oil bitumen production is inevitable. The tables were produced by the Ministry of Oil and represent the state of their fields.

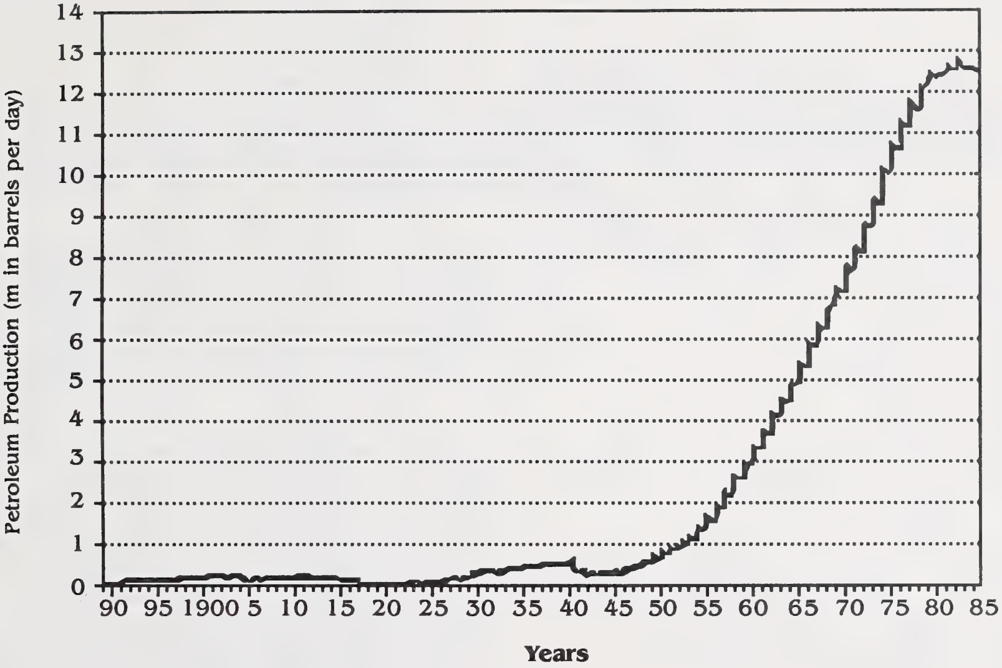


Figure 1. Petroleum production in the U.S.S.R.

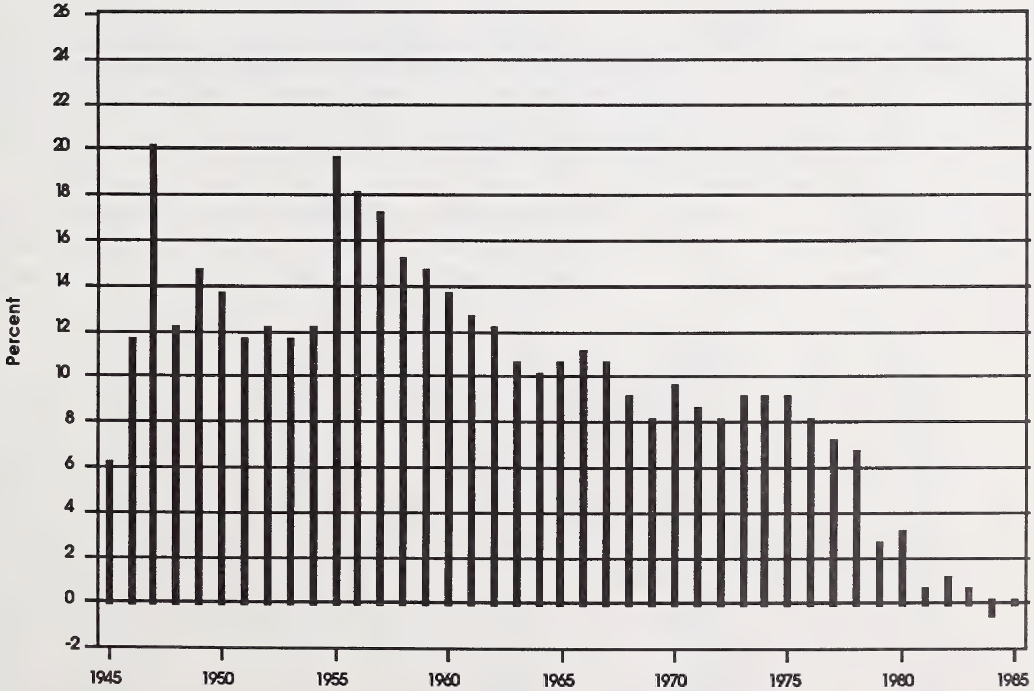


Figure 2. Declining growth of oil production (percentage increase over previous year).

Enhanced Oil Recovery

Since 1975, 'Oil Production Using New Methods' (Figure 3) has grown from virtually nil to over 50 million tonnes per year and the projected production from new methods is expected to reach 97 million tonnes/year in the year 2005.

These 'new methods' include a variety of enhanced recovery technologies, they include:

- infill drilling
- oil mining
- hot water injection
- in situ combustion
- surfactant use
- high pressure gas (air, CH_4, CO_2) injection
- high pressure steam injection
- cyclic steam injection
- combined in situ combustion and steam injection
- combined steam soak and waterflood
- steam-gas generator stimulation
- alkali and caustic solution
- micellar solution
- H_2SO_4 flooding
- polymer solutions
- combined steam injection with downhole heating
- microbe stimulation (lab testing)

The best results have been through hydrodynamic and thermal methods, with cyclic steam injection, steam drive, in situ combustion, oil mining (thermal assisted) and steam-gas generator stimulation being the most successful methods.

The conclusions reached from these tables indicate only one thing: The U.S.S.R. is seriously going to have to consider secondary and tertiary recovery methods as well as developing other sources of heavy oil and bitumen. The opportunity for AOSTRA to license technology to the Soviet Union appears a distinct possibility. Soviet scientists have recognized the importance of E.O.R., heavy oil and bitumen production and have done considerable research over the past 15 years.

Table 1. Development of Oil Deposits by Oil Ministry. This table indicates the phenomenal growth of the Soviet oil development from 37.8 million tonnes in 1950 to 593.4 million tonnes in 1987. The recent trends show a steadily increasing water-oil ratio and decreasing production of average oil per well per day. Average daily production per well has dropped from a high of 21.7 tonnes/day in 1975 to 13.3 tonnes/day in 1987, with a steadily increasing amount of injected water to oil produced.

Year	Oil production (with gas condensate) mln tonnes	Total wells	No. of production wells per one injection well	Injected water per 1 t of oil m^3/t	Water-oil ratio	Average oil from 1 well t/day
1950	37.8	20186	41.5	0.24	1.92	6.2
1955	70.7	29807	15.4	1.2	1.69	8.1
1960	147.7	37014	11.1	1.3	1.27	12.4
1965	242.8	45924	8.5	1.4	0.63	17.0
1970	353.0	56514	8.7	1.6	0.76	19.6
1975	490.8	71875	7.1	2.0	0.90	21.7
1980	581.7	90651	5.6	2.6	1.34	21.5
1981	587.6	97505	5.6	2.8	1.49	20.2
1982	592.6	104465	5.5	3.1	1.64	19.2
1983	596.3	112401	5.3	3.4	1.85	18.1
1984	592.4	120891	5.2	3.6	2.06	16.7
1985	570.7	128988	5.1	3.9	2.31	15.2
1986	586.6	139662	5.0	4.1	2.50	14.4
1987	593.4	153376	4.9	4.4	2.70	13.3

Table 2. Development of Oil Deposits in Western Siberia. The figures for Western Siberia are even more dramatic, as average oil/day per well has decreased from a high of 118.7 tonnes/day in 1975 to 27.9 tonnes/day in 1987. The water-oil ratio is also steadily rising.

Year	Oil production (with gas condensate) mln tonnes	Total wells	No. of production wells per one injection well	Injected water per 1 t of oil m^3/t	Water-oil ratio	Average oil from 1 well t/day
1965	0.95	47	10.7	0.02	0.01	23.2
1970	31.4	1211	5.0	1.43	0.05	89.0
1975	148.0	4362	4.4	1.75	0.17	118.7
1980	312.6	13737	4.3	2.08	0.35	80.2
1981	334.4	17089	4.1	2.23	0.46	69.6
1982	352.9	19172	3.6	2.46	0.62	67.1
1983	370.1	25043	3.5	2.86	0.80	54.1
1984	377.9	28387	3.6	3.04	1.04	48.6
1985	366.0	40934	3.5	3.30	1.29	32.9
1986	384.6	44132	3.5	3.69	1.52	32.1
1987	403.0	51909	3.9	3.55	1.96	27.9

Table removed, considered confidential.

Table 4. Distribution of Number of Wells and Oil Recovery by Well Production. This graphic is a representation of Table 3 by showing the number of wells and total production for 4 ranges between 0 – 5, 5 – 25, 25 – 50 and 50+ tonnes/day.

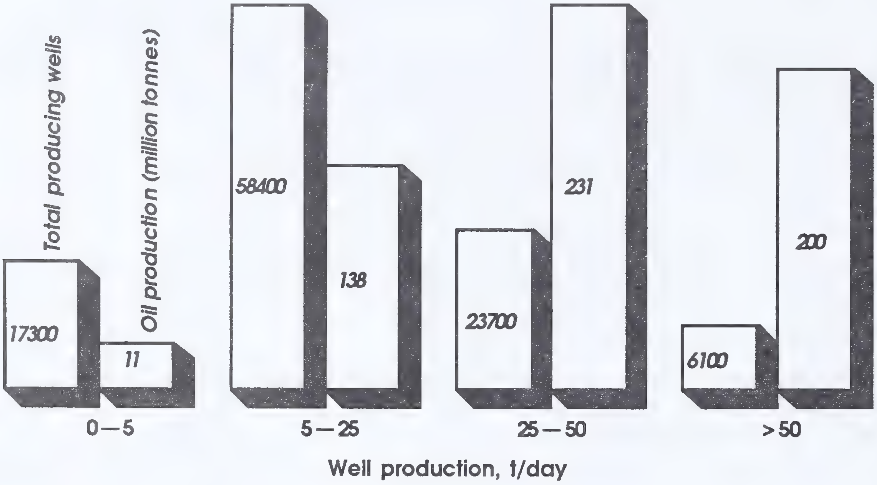


Table removed, considered confidential.

Table 6. Final Recovery by Region. This table represents the U.S.S.R. perception of oil recoveries in other areas of the world. They feel they still have higher recoveries than all other world producers.

Region, country	Final recovery
USA and Canada	0.33–0.37
Latin America	0.26
Europe	0.37
Africa	0.27
Far East	0.24
Iran	0.16
Saudia	0.35
U.S.S.R. Oil Industry (projected)	0.45

Table removed, considered confidential.

Table 8. Oil Recovery for Deposits More Than 25 Years Old. Of significance is the percentage of water being produced in some fields. Water cuts range from 69% to 96%, which would seem to be uneconomic. Again, as the older fields run down and the production costs of producing 90% water are taken into account, the future of E.O.R. and bitumen recovery become attractive.

Deposit	Viscosity mPa•sec	Oil recovery	
		Projected	Current (% of water)
Abdrachmanovskaya	2.74	0.568	0.436 (80)
South Romashkinskaya	4.97	0.543	0.414 (84)
Almentievskaya	4.0	0.548	0.427 (69)
Minnibaevskaya	2.8	0.560	0.442 (84)
Bavlinskoe	2.4	0.593	0.491 (91)
Tuimazinskoe	2.55	0.608	0.541 (95)
Shkapovskoe	0.95	0.58	0.53 (96)
Muchanovskoe	0.77	0.59	0.52 (80)
Dmitrievskoe	1.48	0.65	0.51 (82)
Kuleshovskoe	0.65	0.62	0.56 (94)

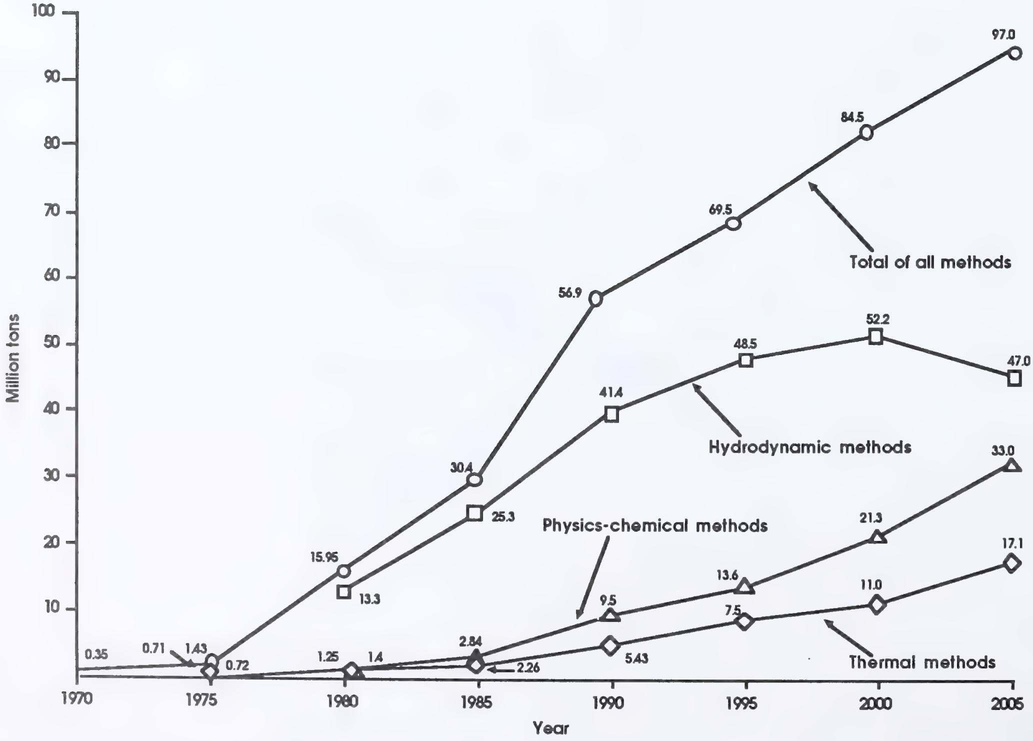


Figure 3. Oil production in the U.S.S.R. by new methods (MNTK).

BITUMEN

In continuing their work to define new supplies of oil, the U.S.S.R. has started a significant effort in defining and developing technology for their huge bitumen deposits. Scientists have identified deposits in all areas of the U.S.S.R., a number in developed areas close to infrastructure and markets whose development would be of economic and social benefit.

Literature searches have indicated that Soviet scientists have done a great amount of theoretical work on bitumen, geochemistry and deposition. The definition of bitumen varies in Soviet work, but Meyerhoff and Meyers (1987) have related the definitions used by the Soviets to those recommended by UNITAR. These are:

1. "Heavy and extra-heavy crude oils and bitumens are petroleum or petroleum-like liquids or semi-solids occurring naturally in porous and fractured media. Bitumen deposits are also called tar sand, oil sand, oil impregnated rock and bituminous sand (kiree)".
2. These crude oils and bitumens may be characterized first by viscosity and then by density.
3. Viscosity should be used first to differentiate between crude oils on one hand and bitumens on the other. Subsequently, density should be used to differentiate among extra-heavy crude oils, heavy crude oils and other crude oils.
4. Bitumens have viscosities greater than 10,000 mPa. Crude oils have viscosities less than or equal to 10,0000 mPa. These viscosities are gas-free as measured and referenced to original reservoir temperature.
5. Extra-heavy crude oils and bitumen have densities greater than 1000 kg/m^3. Heavy crude oils have densities from 934 to 1000 kg/m^3 at 15.6°C and atmospheric pressure.
6. Crude oils with densities less than 934 kg/m^3 are classified as medium or light crudes.

From our experience the people we talked to generally considered natural bitumen to have greater than 10,000 mPa viscosity and a density of 1000 kg/m^3 or more. Heavy oil and bitumen often is considered oils which cannot be produced by water flood methods and need thermal assistance to be produced.

Table 9. Physicochemical Properties of the Principal Classes of high Viscosity Oils and Natural Bitumens. This table shows the physicochemical properties of high viscosity oils and natural bitumens as adapted from Klubov (1983). Oil content is the basic factor in their classification.

Class of natural bitumen	Content (%)		Viscosity (Pa.s)	Density (g/cm^3)	Solubility in $CHCl_3$
	Oils	Asphaltene-resin Components			
High-viscosity oil	65	35	0.05–2	0.935–0.965	Soluble
Maltha	65–40	35–60	2.00–20	0.965–1.030	Soluble
Asphalt	40–25	60–75	20.00–1000	1.030–1.100	Soluble
Asphaltite	<25	>75	>1000	1.050–1.200	Soluble
Kerite	<10	>90		1.070–1.350	Partly Soluble
Oxykerite	1–5	>95		1.050–1.250	Partly Soluble
Anthraxolite	0	100		1.300–2.000	Insoluble
Oxokerite	50–100	50–100		0.850–0.970	Soluble
Huminokerite	0–2	0–62		1.250–1.500	Slightly Soluble

Source: Adapted from Klubov, 1983, and Khalimov et al., 1985.

The terms maltha, asphalt and asphaltite are often referred to in Soviet literature and are commonly used by field personnel.

Soviet scientists indicate two lineages of heavy oil and bitumen development. The Kir or regressive lineage is characterized by the loss of light fraction of the parent oil over a period of 10 million years or less. They form surface stratiform, kirized bitumens and asphalt lakes. The second is the platform or progressive lineage, characterized by thermal metamorphic changes which occur over a long period of time, up to 100 million years. The lineage is rich in heavy metals and the end product of oil degradation could very well lead to sedimentary, stratified metallic ore deposits.

As a result of the genesis of bituminous deposits, the physical characteristics of heavy oil and bitumen deposits are of three basic types:

a. Stratiform or Bedded Deposits (Tataria, Olenek, Athabasca, Orinoco).

b. Surface Kir Deposits – associated with live seeps, asphalt lakes, mud volcanoes (Baku, Sakhalin Island).

c. Vein Deposits – solid state bitumen found in veins.

The stratiform and surface kir deposits are the most common and deposits of these types were visited in the Soviet Union (i.e. Tataria, Yarega, Baku, Okha Sakhalin Island).

Goldberg (1981) describes the directions and goals of the U.S.S.R. work on bitumen as such:

> "Natural bitumens should be considered as a new kind of material not only from the point of view of the present, but also of the future achievements in the field of engineering and technology of their production and processing, and also of possible new ways of using them. At the present time several directions have been marked out, in which investigations in the field of developing natural bitumens in the U.S.S.R. and abroad are being carried out."

a. Obtaining hydrocarbon raw material (synthetic crude);

b. Replacing artificial petroleum bitumens with natural in several branches of industry (road construction, electrical engineering, chemicals).

c. Extraction of vanadium, nickel and other valuable metals from bitumens and highly tarry petroleums.

d. Creation of qualitatively new materials, in particular, building materials based on natural bitumen and bituminous rocks.

e. Use of ore-thermal products as raw materials."

During our trip we had very basic discussions with Soviet scientists who were working on the above mentioned goals. Most was experimental work on thermal methods for bitumen production and various research on heavy metal extraction. Some positive concrete results have been achieved, such as the development of bitumen with sand ("kiree") for road construction in Kazakhstan and Tataria.

Detailed papers on Soviet work on thermal methods and bitumen are available in AOSTRA's database. Excellent papers for general review of bitumen in the U.S.S.R. include **Meyerhoff** and **Meyer** (1987) – Geology of Heavy Crude Oil and Natural Bitumen in the U.S.S.R., Mongolia and China; **Goldberg** (1981) – Natural Bitumens of the U.S.S.R.; and **Fane** (1984) – Heavy Crude Oil and Tar Sands Resources in the U.S.S.R. (UNITAR).

GEOLOGY AND RESOURCES

Bitumen deposits are found throughout the U.S.S.R. Figure 4 is a map of the bituminous basins in the U.S.S.R. (from Khalimovs et al. 1983). They identify four major areas of concentration of natural bitumens as the following tectonic types:

a. basins of marginal deeps (Leno-Anabarsky).

b. basins of the ancient platform deeps (Volga-Urals, Tungussky, Timano-Pechorsky).

c. basins of the intermountain depressions of epigeosynclines and epiplatform origins (Fergansky, Sakhalino-Okhotsky Raono-Kurinsky, Yuzhno-Caspiysky).

d. basins of continental margins (Barents-Sea).

Deposits in the Volga-Urals, Timano-Pechorsky, Sakhalino-Okhotsky and Yuzhno-Caspiysky were visited during our trip. Figure 5 is another map indicating the more common names of heavy oil and bituminous deposits in the U.S.S.R.

The total amount of resources of heavy oil in the U.S.S.R. has not been determined. However, rough estimates range from 70 billion tonnes to 280 billion tonnes of bitumen in place. The known registered reserves of natural bitumen are 12.7 billion tonnes as indicated below. These are the latest figures available as indicated by Gosplan.

Table removed, considered confidential.

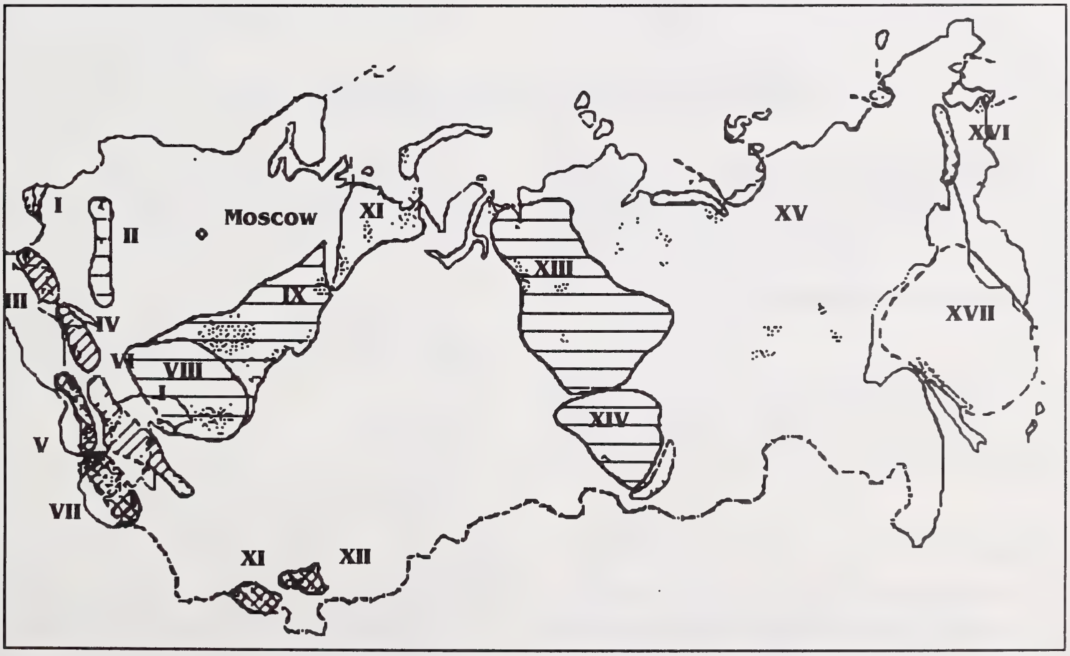


Figure 4. Basins: I. Pre-Carpathsky; II. Dnieprovsko-Donetsky; III. Severo-Chernomorsky (Northern Black Sea Region); IV. Azovo-Kubansky; V. Riono-Kurinsky; VI. Sredne-Caspiysky (Middle Caspian Sea Region); VII. Yuzhno-Caspiysky (Southern Caspian Sea Region); VIII. Pre-Caspiysky (Pre-Caspian Sea Region); IX. Volgo-Uralsky (Volga-Urals); X. Timano-Pechorsky (Timan-Pechora); XI. Afghano-Tajiksky; XII. Fergansky; XIII. Tungussky; XIV. Irkutsky; XV. Leno-Anabarsky; XVI. Penzhinsky; XVII. Sakhalino-Okhotsky (Sakhalin-Okhotsk).

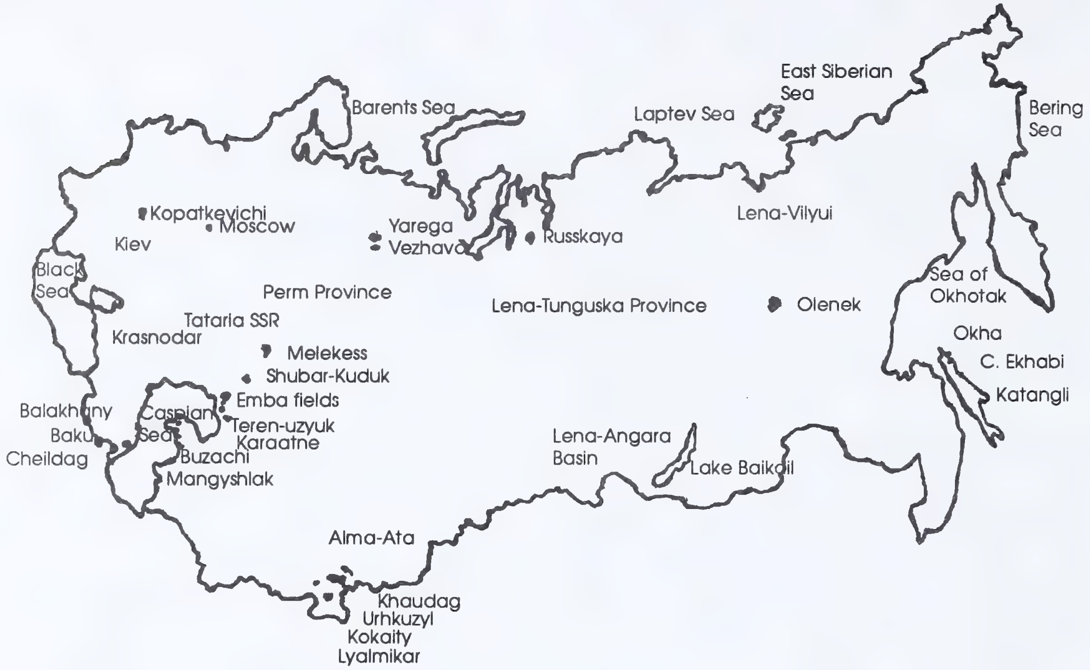


Figure 5. Major bituminous deposits of the U.S.S.R.

Work done to date has identified over 400 deposits with possible commercial potential – the majority of these being in the Volga-Ural basin in Tataria. Depths range from surface to 1200 meters, however, the majority are at less than 400 meters.

Dvorets et al. (1984) reported that 65% of all heavy oil and natural bitumen deposits contain 3–5% vol bitumen, 21% contain more than 5% vol. bitumen and 16% contain less than 3% vol. bitumen.

PRODUCTION

The only commercial production of bitumen occurs at the Yarega Oil Mine which produces around 1500 tonnes/day or 550 k tonnes per year. Another 2000 tonnes/day or approximately 730 k tonnes per year is produced from pilot projects, however, these pilot projects are often sporadic in their performance so the production figures vary widely from year to year.

In Kazakhstan, 2 m tonnes per year of ("kiree") bitumen with sand is produced for road construction, and in Tataria, "kiree" is also produced but on a much smaller scale.

New production in the near future will come from a new oil mine at Yarega and probably from developments in Tataria and possibly Baku.

ECONOMICS

Some economic analysis has been done on the production and upgrading of bitumen in the U.S.S.R. Khalimov et al. (1983) states the following:

> "During the last decade the interest to the solution of the problem of investigation and producing natural bitumen has increased. This is caused not only by the fact that the resources can play an essential role in improvement of the fuel – energy balance of the total country in the future but also

with detection of capability of the diverse use of natural bitumen in various branches of the national economy.

The economic evaluation of natural bitumen will be more complete, if one will evaluate natural bitumen as a fuel used instead of "energy" coal produced in the basins of the European part of the U.S.S.R. The comparative analyses showed, that the mining and open pit methods of producing bitumen from deposits with even unfavorable geological characteristics, are more profitable than production of coal in the regions, located not far from the centre of the country, (1.7–2.5 times more profitable).

The multicomponent composition of natural bitumen causes the necessity of its more extensive processing, as compared to conventional oil. On average it requires 2–2.5 times higher expenses in comparison with processing traditional oil". However, this is still cheaper than the costs of coal from the European part of the U.S.S.R. on a cost per B.T.U. basis.

Studies done by the Soviets indicate that the production of liquid fuel from bitumen was significantly better than the same products from coal. The produced costs for products obtained from lignite coal versus bitumen were as follows:

Lignite

Capital costs	291.9%
Prorated costs for product	151.0%
– Automotive Gasoline	181.2%
– Diesel Fuel	194.4%
– Boiler Fuel	113.8%

Surguchev et al. (1983) indicated that calculated costs to produce tar sands (bitumen) by in-situ mining was \$75–\$100 (U.S.) per cubic meter. He also indicated that the cost of production of bitumen by thermal methods was even lower.

In conclusion, it seems that the development of bitumen deposits in European Soviet Union would be much more economic than producing coal for the old coal pits. The socio-economic factors involved in phasing down the coal pits and switching to bitumen production would be tough from the point of view of the coal workers, however, through retraining, etc., the long term economic benefit of developing their heavy oil and bitumen resources would be beneficial.

If this does turn out to be the case, then the involvement of AOSTRA through licensing technology, possible joint ventures or consultant contracts, would be advantageous. AOSTRA's involvement in the early stages of this development could reap great rewards for the future in terms of money, international reputation and goodwill.

MOSCOW

The "Interbranch Scientific Technological Complex, Oil Recovery" (MNTK) were the hosts of our trip. This organization's headquarters are in Moscow, with branches in many areas of the U.S.S.R. It is one of 22 organizations of science, technology and academia in the Soviet Union.

MNTK now covers all aspects of oil recovery i.e. research, lab pilot projects, field testing, commercial production and production of equipment. This was not always the case, prior to the reorganization in 1986, many ministries were involved in the process. This caused many bureaucratic headaches as different ministries had separate budgets and objectives, therefore, obtaining a smooth running, efficient program was difficult.

MNTK is now responsible for the majority of enhanced recovery technology in the U.S.S.R. Their mandate is:

a. Increase the efficiency of existing deposits (waterflood technology);

b. The creation of new efficient methods to increase oil production;

c. Update technology and build equipment for more efficient oil recovery;

d. Technology licensing organization, responsible for selling and licensing their technology to the world and also acquiring and implementing new technology from abroad.

The mandate of MNTK encompasses a wide range of activities which are very similar to those of AOSTRA.

During our initial talks with MNTK, they made a presentation outlining the activities, budgets accomplishments and problem areas of their organization. This presentation prompted immediate questions about AOSTRA, concerning their budgets, accomplishments and areas of future research. After we presented literature concerning AOSTRA's activities, it was quite clear that both MNTK and AOSTRA had mutual goals for the future.

INTERBRANCH SCIENTIFIC TECHNOLOGICAL COMPLEX OIL RECOVERY, MNTK "NEFTEOTDACHA"

The following tables give a synopsis of the nature of business of MNTK.

Intersectural Scientific and Technological Complex MNTK "Nefteotdacha"

All Union Scientific-Research Oil and Gas Institute
(Head Organization of MNTK)

Main Organizations

NPO Sojuztermneft (Krasnodar)	NPO Sojuzneftepromhim (Kazan)	NPO Sojuznefteotdacha (Ufa)	Tatneftebitum (Bugulma)
Scientific-Research and Design Institute	Scientific-Research and Design Institute	Scientific-Research and Design Institute	Scientific-Research Dept.
2 Oil Fields	Pilot and Semicommercial Plant for Chemicals Production	Oil Fields	Oil (Bitumen) Deposits
Equipment Manufacturing (Plant)	Services	Services	Pilot-Experiment Plant
2 Contracting Organizations			

Organizations of Other Ministries

Academy of Science of U.S.S.R. (7 institutes)

Ministry of High Education (2 Institutes)

Other Ministries Organizations)

Organizational Activity of MNTK "Nefteotdacha"

MNTK Council	Interbranch problems of technological technique and economic relations
Interbranch commissions	Scientific level and priority directions: • Fundamental research • Technical support • Small scale chemistry • Automization
Operative groups	Analysis, scientific and methodological help with technology implementation (Karazhabas, Gneditchi, Usa)
Associated laboratories	VNII-IPM, Academy of Science of U.S.S.R. VNII-IFZ, Academy of Science of U.S.S.R. VNII-MGU, Moscow State University VNII-MING, Giprovostokneft
Coordination of research	More than 130 organizations annually
Plans of MNTK	100 implementing organizations 12 ministries and offices; from fundamental research to implementation
Training and study programs	92 graduate students, 100 engineers

Production Activity of MNTK "Nefteotdacha"

Type of activity	Results
Production of oil and bitumen	2.2 mln tons of oil; 5000 tons of bitumen
Testing of EOR technologies (oil and bitumen)	13 technologies: steam with foam, liquid phase oxidation, CO_2, polymers, steam-water injection system technology
Implementation of methods and technologies	30 technologies 9 mln tonnes by EOR methods, 30 mln tonnes by hydrodynamic methods
Production and testing of new equipment	Portable steam-generators, gas-steam generators Insulated pipes, filters, packers, registration apparatus
Production of new chemicals	Inhibitors of paraffin and salt depositions, etc.
Construction	13 producing fields, 3 research-production sites Investment 100 mln r.
New automatic equipment	Pressure, temperature gauges, etc.

Scientific Activity of MNTK "Nefteotdacha"

Type of research	Results
Study on structure of oil and bitumen deposits	Water containing low productive high viscous under gas cap abnormal bituminous
Fundamental and frontier research Synthesis of chemicals	1 year areas: in situ production of working agents, microbiology, wave (seismic), biopolymers, compositional steam-water layering
Applied research	Technology, systems, relations, analysis
Project, experimental design	Samotlor, Karajanbas, Russkoe, etc., equipment, apparatus
Prognosis on oil and bitumen production	Perspectives 1991–1995, 2010 potential
Development of automatic and control systems	Control system of EOR data Control system of reserves Lab control system, etc.
Analysis of mathematical support, technical assignments to adjacent branches	52 types of new technical means 10 types of chemicals
Economic analysis	Evaluation of effectivity design
Instructions and manuals	More than 20 manuals and instructions

R&D Budget of MNTK "Nefteotdacha" in 1988 (thousand rubles)

	Experimental production	R and D	R and D	
			MNTK	Subcontractors
All Union R&D Institute		10909	5210	5699
Souztermneft	34650	5569	2975	2594
Souzneftepromchim	1162	4300	1806	2494
Souznefteotdacha	3500	4328	2024	2304
Tatneftebitum	2385	300		300
MNTK Total	41698	25406	12015	13391

Basic Technologies at MNTK "Nefteotdacha"

Basic technology	Increase of oil recovery	Oil produced in mln tonnes		
		1988–1990	1991–1995	2000
1. Layering (water-steam)	2–3 times	27.6	47.4	9.3
2. Hydrodynamic methods	3–10%	80.1	153.9	27.8
3. Steam injection	3–4 times	7.9	24.1	14.2
4. Combustion methods	3–4 times	2.0	4.9	1.8
5. Gas injection	8–12%	4.6	22.0	10.2
6. Polymer flooding	10–12%	2.5	15.8	6.3
7. Oil pool efficiency	3–7%	3.8	14.8	4.6

Research on Future Technologies for Hard-to-Recover Oil Reserves

Reserves	Technologies
High water cut	Carbon dioxide Micellar solution (with water) Vibration Bio-steam injection, biopolymers
Low permeability	Primer recovery Water solution with steam injection, water-gas mixtures Weakening of molecular bounds
High viscosity oil	Thermal methods Thermo-shaft drainage Bio-method Electro-magnetic
Thin pay zone and under gas cap	Fluid barriers on gas-oil and oil water contacts Selective water flood
Abnormal pay zone	Biodesolution Dissociation of rock

Oil Produced by EOR Methods in 1986–2000 in million tonnes per year

	1986	1987	1988	1990	2000
Thermal	2.8	3.1	3.5	5.2	12.4
Steam drive	1.5	1.7	2.0	3.5	8.2
Steam cycling	–	–	–	–	–
Combustion	0.3	0.4	0.5	0.7	2.5
Hot water	1.0	1.0	1.0	1.0	1.0
Gas	0.5	0.6	0.11	2.4	10.3
CO_2	0.5	0.6	0.7	2.2	7.6
Carbon acid	–	–	0.04	0.2	2.7
Physics-chemical	1.7	2.0	2.5	6.8	12.3
Polymers and micellars	0.5	0.5	0.6	1.0	4.4
Sulfur acid	0.8	0.8	0.8	0.8	1.1
Alkalines	0.1	0.2	0.2	0.6	1.1
Steam-water cycling	0.3	0.4	0.6	1.3	2.7
Compositional (IHN)	–	0.1	0.3	1.1	2.0
Combined	–	–	–	2.0	1.0
Total	5.0	5.7	6.7	14.4	35.0
Hydrodynamic	26.9	30.0	42.5	39.0	38.4
Total	31.9	35.7	59.2	53.4	73.4

Target Problems of MNTK "Nefteotdacha"

Exploration of unique deposits

- Russkoe
- Usinsk
- Karazhanbas
- Tenghiskoe
- Talinskoe
- Samotlor
- Hariaghinskoe
- Fedorovskoe
- Liantorskoe
- Mordovo-Karmalsk

Research in New Technologies and Technological Systems

- Hydrodynamic methods (Western Siberia)
- Steam-water injection (Karazhanbas)
- Steam physical-chemical methods (Karazhanbas)
- In situ generation of flue gases (Gneduntci)
- Microbiological (Bonduzhskoe)
- Gas injection (Tenghiskoe)
- Compositional steam-water methods (Romashkino)
- CO_2 with polymers (Radaevka)
- Water-gas injection (Samotlor)
- Thermoacoustic, seismic

Preconditioning of Near Well Areas

- System injection of surfactants
- Thermoacoustic methods
- Polymer-acid system
- Hydrochloric acid

Automization and Control

- Automization of design of oil fields exploration
- Automatic system of control for technological processes (experimental area in Karazhanbas)

Technology and Research in EOR Exceeding International Level

Industrial Technologies

- Water-steam layering (Kenkiak, Usa and others)
- Polymer flooding (Kalamkas, Yablonevskoe and others)
- Thermoshaft (Yarega)
- Barrier flooding (Samotlor), block systems
- Cyclic flooding (Samotlor, Romashkino and others)

Research-Industrial Experiments

- Thermoacoustic methods (Uzen, Fedorovka)
- Microbiological methods (Bonduzhnoe and others)
- In situ oxidation with generation of CO_2 and nitrogen (Gnedintcy)
- System influence on low permeability pay zone (Sutominskoe, Muravlenkovskoe and others)
- Compositional water-steam layering, etc. (Sovetskoe, Samotlor, Romashkino)

Applied, Fundamental and Frontier Research

- Thermo-alkaline methods (All-Union Scientific-Research Oil and Gas Institute (VNII))
- Compositional water-steam layering for water cut (VNII)
- Mathematical modeling of new methods (VNII)
- Chemical-biological methods (Academy of Science of the U.S.S.R.)
- Redislocation of leftover oil (Academy of Science of the U.S.S.R., Kubanskiy State University, VNII)
- Tracing of firefront from the surface

Modern and Future Methods of Oil Recovery

Existing		Future	
Used by industry up to 1985	**Planned for implementation in 1986—1990**	**At test stage**	**Research**
Primary recovery	Steam injection	Water-gas flooding with layering	Water-gas layers
Water flood	Polymer flooding	Combustion	Thermo-alkaline flooding
Cyclic flooding, thermal	Steam drive, cycling	Microemulsions	Microbs
Layering	Sulfur acid	Alkalines flooding	Redistribution of oil saturation
		CO_2 flooding	Electromagnetic

Average Final Oil Recovery

43–45%	45–50%	50–60%	60–65%

During the course of our trip we had three opportunities to discuss the nature of the oil business in the U.S.S.R. and Canada with the principals of MNTK. These people were:

- Professor Dr. Michail L. Surguchev – Director
- Dr. Arkady A. Bokserman – First Deputy Director
- Boris S. Lobanov – First Deputy Director
- Professor Dr. Gadel G. Vakhitov – Deputy General Director
- Dr. Yusuf G. Mamedov – Head of Laboratory, Analysis of Foreign Experience

There were often other people in the meetings, whose names are listed on the contact list.

These meetings proved to very interesting and informative. Listed, in point form are some of the comments:

DISCUSSIONS

U.S.S.R.

- MNTK is now an all encompassing unit which is involved in all aspects of oil and gas development both upstream and downstream.
- U.S.S.R. oil production will be fairly constant to 1998 (i.e. 12.5–12.8 m bbl/day 1.63 m t/d).
- However, production per well per day is dropping every year and will continue to do so, therefore, they must find ways to increase the total recovery of each reservoir.
- Up to the mid seventies, the Ministry of Oil and Gas was only concerned with primary production and exploration. They were awash in cheap oil and didn't really think much about enhanced recovery.
- Now all their easily producible supergiant and

giant fields (Western Siberia, Romashkino, etc.) are in declining production. Newly found fields are much smaller with higher cost production. These new fields barely make up for the declining production of the giants.

- With the levelling off of Soviet oil production and the drop in the international price of oil, the amount of hard currency generated by the Soviet Union has been cut by 40–50%. The results of this reduction of hard currency is now being felt in the U.S.S.R. through the massive shortages of goods, increased inflation and economic and political unrest. Institutes like MNTK realize that one of the cornerstones of re-establishing their oil industry is the introduction of E.O.R. and the production of heavy crudes and bitumens.
- At present oil pricing in the U.S.S.R. varies by deposit type and technology used for recovery. Therefore, numerous areas operate at a loss. This system tends to negate creativity and initiative to upgrade the resource or run a more efficient operation. In fact, in Okha, their production costs are about 60–70% greater than the price they received for their oil. The difference is made up by Moscow in grants, but to a maximum, therefore, the more they produce, the greater the loss; thus they have absolutely no incentive to produce more than their target. There is no incentive to improve methods, or innovate new ideas.
- In 1990, it is anticipated that the oil in the U.S.S.R. will be sold at world price, both inside and outside of the U.S.S.R. The internal subsidized price will be lifted thus making oil fields compete on a stand alone basis. They feel that many uneconomical fields and factories will be closed, but that is one of the consequences of improving their economy.
- At world price, institutes will be able to sell excess production (above their target) on the World Market for hard currency. This will add incentive to improve production efficiency and implement new creative methods of production. The hard currency will be used to buy updated Western equipment to further increase production (joint venture increases are anticipated).
- The changes in the U.S.S.R. in the past year have been phenomenal, things are moving so fast that a lot of managers etc. cannot cope, because they are used to the old bureaucratic system. Managers have no background in economics etc. and they are afraid and uncertain of what to do.
- MNTK considers now as a time of transition, they feel it will take three years to transcend from the old to the new system. They consider now as the worst time because of the chaos and uncertainty involved in moving from the old to the new.
- The reorganization was implemented to cut down on the bureaucratic mess and to start running their economy as a business, with responsibility for profits and losses.
- The person responsible for economic change is L.I. Abalkin, Deputy Chairman of the Council of Ministers, he has given himself a 2 1/2 year deadline to implement change in the U.S.S.R.
- The great need now, is hard currency to buy Western equipment. MNTK is also very interested in how groups like AOSTRA and the ERCB function within the Provincial Government. They need ideas and models to help improve their own system.
- They want to learn business principles – "We want to run our economy as a business, not a group of competing mini states which our ministries have become".

AOSTRA

- Because of their experiences at UNITAR and their literature searches, they consider AOSTRA as "The world leader in developing technology for the recovery of heavy oil and bitumen". Thus they very much want to set up a good working relationship with AOSTRA.
- They feel that theoretically they are equivalent to the West, but when it comes to pilot plants, commercialization and building of equipment they are lacking. They need Western help in setting up and running E.O.R. projects. Not only equipment but consultants, etc.
- They are very interested in the exchange of experts for training and work. MNTK said they can provide offices, housing, etc. for any expert

who would want to work in the U.S.S.R. They are very interested in discussing an exchange program with AOSTRA.

- With the increase of oil prices to world levels, they are very interested in joint ventures with AOSTRA or any Alberta company to produce oil by thermal methods to sell on the open market. Profits would be split between the joint venture partners.
- The top principles of MNTK would like to visit Alberta and AOSTRA as soon as possible to discuss the future cooperation and business ventures which may occur between MNTK and AOSTRA.
- They would appreciate meetings with the Department of Energy, ERCB and the Department of Environment to understand how these agencies function and how they relate to the oil industry.

The meetings were very interesting and informative, the atmosphere was completely open (something I didn't expect) and candid.

TALKS WITH DR. G.G. VAKHITOV, DEPUTY GENERAL DIRECTOR, MNTK

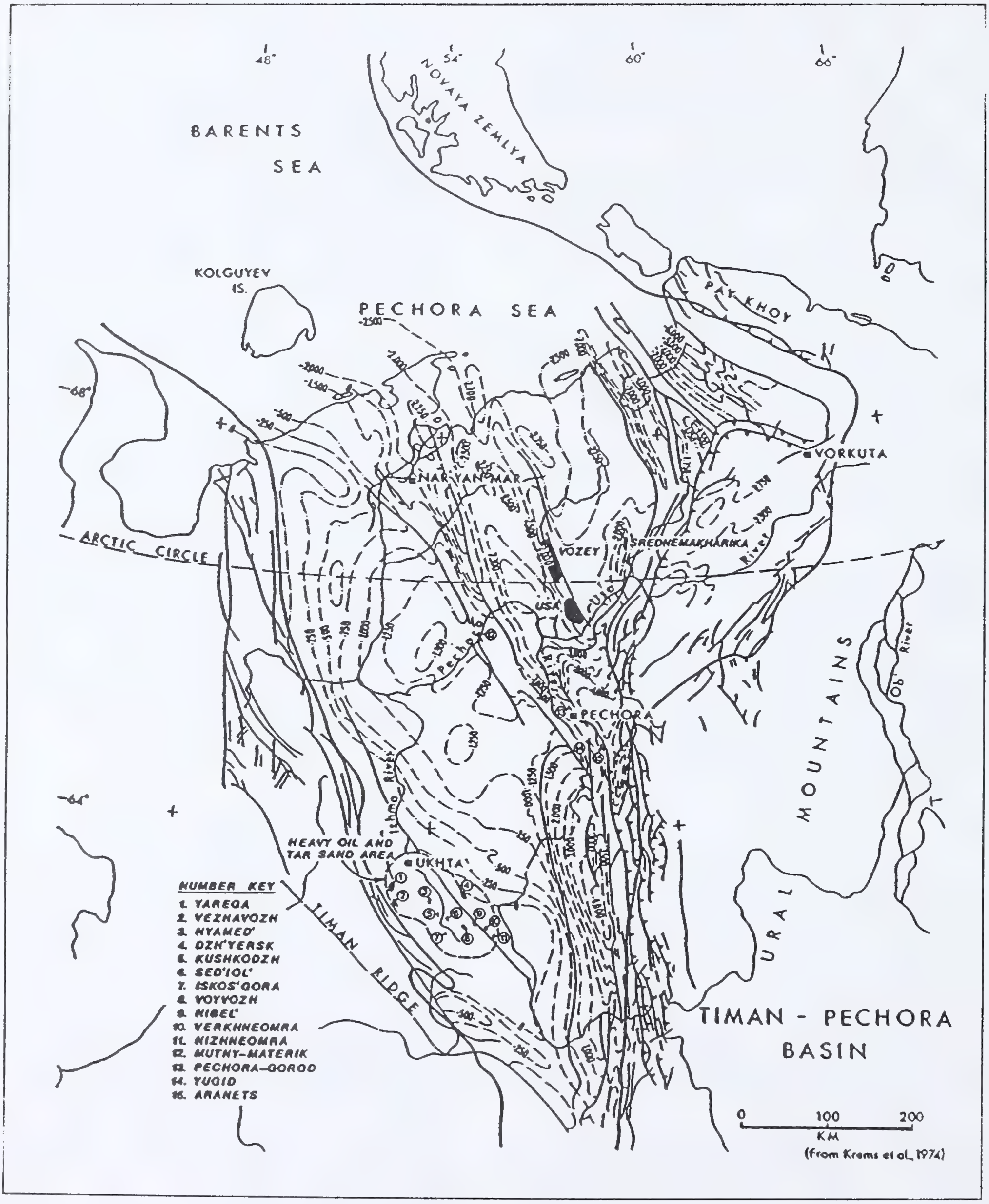
We had some interesting talks with Dr. Vakhitov concerning AOSTRA and the future development of heavy oil and bitumen in the U.S.S.R. Dr. Vakhitov is presently the Deputy General Director of MNTK and the former Director Head of their Tataria Institute. His comments were:

- AOSTRA is an organization which supports the development of new technology.
- They want to talk to AOSTRA about using them as a 'broker' or licensing arm for Soviet technology to the world. They realize that AOSTRA has an excellent information arm and its people reach all around the world.
- They are interested in technology exchanges and exchange of scientists to train in each other's country.
- They started a new organization for heavy oil and bitumen only 4–5 months ago mainly because they see a future in heavy oil and bitumen development.
- They have a new plan for a heavy oil refinery and upgrader to handle 1 million tonnes per year.
- They plan to build a 'state of the art' refinery to produce all aspects of oils, fuel oils, paints, gasolines, olefins, etc.
- The factory would be built close to Kazan in Tataria. Kazan is the center of the petrochemical industry in the U.S.S.R.
- The Kazan Academy of Sciences is doing the research into the design and engineering of the project. They have 900 people working on all aspects of bitumen production and upgrading.
- This development is outside of 'Gosplan'. It can be run as an independent business. The products will be sold on the free market for hard currency.
- They need independent financing or a joint venture partner to help in the initial financing. They plan to pay off the refinery through sales to Western countries.
- Products can be shipped from Kazan to the Black Sea and sold to Western Europe. They feel the West Germans are their best bet for a joint venture but they would also be interested in Canadian participation.
- This meeting was interesting because of the enthusiasm shown by Dr. Vakhitov in expressing that projects outside of Gosplan are being encouraged for joint ventures with Western countries.

UKHTA – YAREGA

UKHTA (Komi A.S.S.R.)

Our first field visit was to the city of Ukhta in Komi A.S.S.R., thirteen hundred kilometers northeast of Moscow. It is an industrial city of 130 thousand people with its major industries being railroad and petroleum. Komi A.S.S.R. is the northern-most oil province in Russia. The first indications of oil were observed during the time of Peter the Great (1682–1725) as oil seeps and small bitumen accumulations. The first exploration occurred in the early 1900's around the Yarega River, with extensive exploration and development occurring in the 1930 and 1940's. In fact the oil from Komi was the only source of petroleum for the city of Leningrad during the siege of World War II. The roots of the city of Ukhta and the oil fields of Komi go back to the prison camps built from



Heavy Oil and Bitumen Fields of Timan-Pechora Basin Komi A.S.S.R.

1930 to 1960. Today, there is little or no evidence of the past except in some of the well kept museums at Ukhta and Yarega.

The Timano-Pechorsky Basin is the major geological structure of the area. Within the basin, the major bitumen-heavy oil accumulations occur at Yarega, Usa and Izhma. We visited the development at Yarega and discussed the USA deposit with their Chief Technologist in Ukhta.

Our hosts in Ukhta were the Institute Pechornipineft (Pechora Science and Design Oil Institute) who handle the development of surface thermal methods in Komi. This institute is part of KomiNeft who supervises all oil recovery in Komi province. After reviewing the Yarega field extensively, with discussions and presentations in various offices, we toured the surface facilities used for steam soak and combustion methods and the underground mine at Shaft #1. We also toured a conventional drilling rig which was drilling a deep scientific test hole. The rig, a BU 53/300 the largest produced in the U.S.S.R., is drilling a stratigraphic test hole to a depth of 5 km. We were told that other such tests in the U.S.S.R. are scheduled to reach 12 km.

Pechornipineft has a staff of 1200 including 300 professionals involved in research and development. After discussions with the principles about their work and AOSTRA, we were asked to give a half hour presentation about AOSTRA and heavy oil and bitumen development in Alberta and Canada. The presentation, in the Institute auditorium, was well attended and extended to almost two hours including an extensive question period. The atmosphere was open and candid, with many questions on business, economics, quality of life, etc. We were told this type of presentation would not have been possible even 6 months before.

Yarega Surface Projects

Our host and tour guide on the surface thermal projects was L.A. Ruzin, Head of Laboratory in Thermo recovery, Chief Technologist on development of Usinski method. We discussed both the Yarega and USA projects, results of which are noted.

At Yarega, the surface production by thermal methods is 12 thousand tonnes per year. The first pilots were developed in 1972 and production started in 1974. From 1972 to the present, several methods have been tried, i.e.:

- Steam soak (cyclic steam injection);
- Steam soak followed by combustion;
- Combined method of steam and foam injection followed by cold water injection;
- Chemical methods – need injection of steam and chemicals with injection of foam to regulate and control steam over-ride.

Over the years, work was done on 9, 7 and 5 spot units. The first pilot on a 9 spot system produced from 1974 to 1983. The set up included 1 injector well, 8 producing wells and 6 control wells (temperature measurement only). Well spacing was 50 meters.

Results were:

- The project ran for 10 years and was terminated when the wells produced only water (formation temp 80°);
- Best production occurred between 100–110°C;
- Total sweep of the unit area was 70%, with the corner wells being the problem areas;
- Recovery was 40% of O.O.I.P.

As a result of this pilot, 5 spot and 7 spot pilots were set up. The 9 spot configuration was abandoned because the corner wells did not produce enough. At present, they are satisfied with both pilots but feel the 7 spot system is the best.

Observations and Comments:

- Mr. Ruzin was very interested in AOSTRA's work at Peace River and indicated the pressure cycle steam drive process would seem ideal for this area because of the bottom water layer.
- Equipment was old and not well maintained. The steam units are housed in log buildings and are upward of 30 years old.
- A big problem is sand and sand rings at the bottom of the hole. They tried metallic filters but they didn't work. They now use air to blow out the sand. Once a year compressed air at 15 atm is blown down the hole and the sand is blown out.

- Chemicals and surfactants are pumped directly into the wells from tanks and 45 gallon drums. No monitoring appears to be done, they just pump it in.
- Oil production is measured by opening a production line and measuring the amount of oil accumulated over a period of time (with a watch).
- They pair their steam lines and oil lines and insulate them. They feel the steam lines keep the oil lines warm in the winter, however, it appears to be quite a safety hazard.
- Overall safety conditions appeared very poor and the quality of equipment was very poor. The entire site was littered with broken equipment.
- They expressed that they need access to new equipment to develop their technology in the future. Especially electric monitoring equipment, new steam generators, and new chemicals and surfactants.

In conclusion, the work being done at Yarega with conventional thermal methods was nothing out of the ordinary. They certainly need newer equipment and more modern techniques to improve their results. Their people are interested in AOSTRA's Pressure Cycle Steam Drive method which is used at Peace River and certainly are interested in ways of purchasing new equipment from Canada, however, their access to hard currency is minimal.

USA (Usinskoe) Field

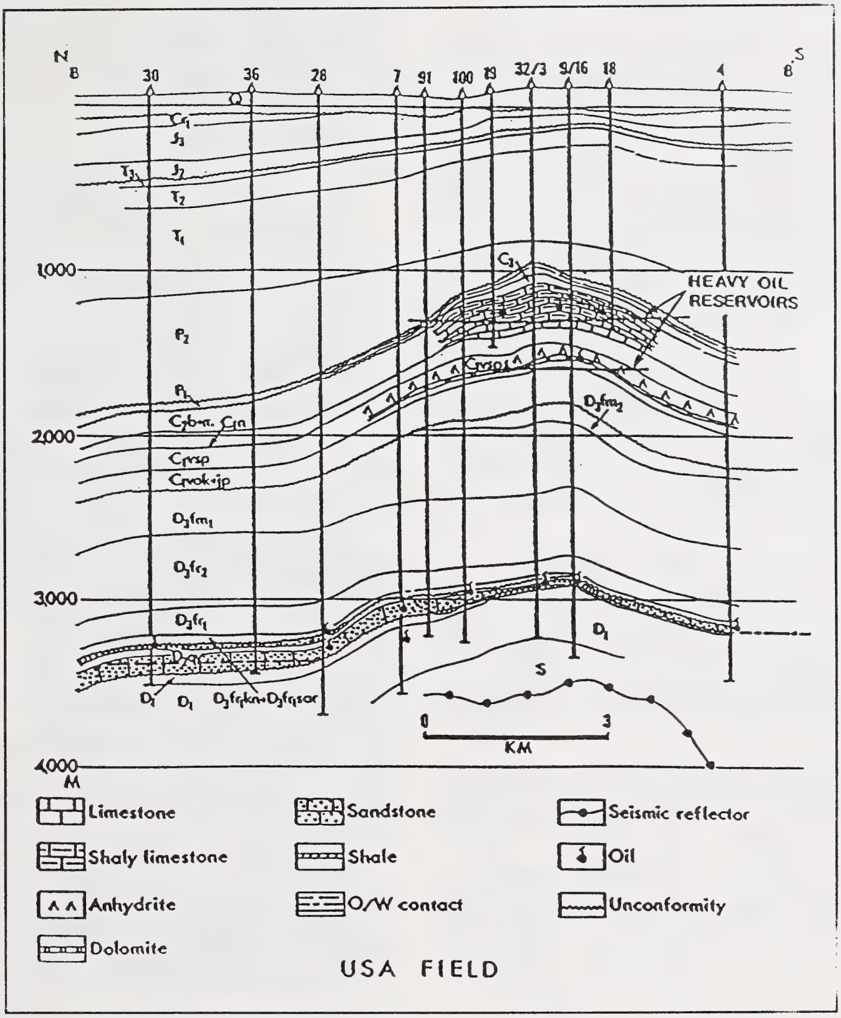
The largest oil field in the Timon Pechora Basin is the Usinskoe Field. This particular field was discussed in some detail because it represents a very thick heavy oil reserve (up to 350 meters) at a depth of 1100–1500 meters. The engineers of Komineft are experimenting with high pressure and temperature steam simulation at depths which are greater than ever before tested. Numerous problems have occurred such as explosions and equipment failure, due to heat and pressure stress and inexperience at working at such depths with high pressure and temperature. The field has three producing horizons. The lower Devonian sands have light oil and are produced by conventional waterflood. The uppermost horizon is the most important from the point of thermal steam stimulation. The following notes are from my discussions concerning the Permian heavy oil deposit.

Area	• 15 km x 10 km = 150 km^2
Depth	• 1100 m – 1500 m
Payzone	• Up to 350 meters
Lithology	• Carbonate (limestone)
Porosity	
Permeability	• Avg. 30–40 md, fracture (uug) porosity up to 100 darcies
Oil viscosity	• 700 cp
Oil Density	• 935 gm/cm^3
Initial temperature	• 25°C
Initial pressure	• 140 atm

- The formation is very fractured with highly complicated fracture patterns. There are large vugs up to 2 meters in diameter which cause drilling problems.
- 30–40% of the oil occurs in macro porosity zones while 60–70% is located in the tight macro porosity zones.
- Shale bands and lenses occur throughout and often impede oil flow.

Production

- Initial wells produced 30–40 tonnes/day because of the high mobility and pressure of the reservoir. Pressure has since dropped to where pumps are now needed.
- 800 wells have been completed and the field is now in full production, at a rate of 3.5 Million tonnes/y using hot water injection.
- Production gas is 22 cu^3 dissolved per tonne of oil. At present this gas is flared at the source, however, new environment laws dictate they can be fined, therefore, Komineft is looking for a joint venture partner to recover the products from the flared gas for future sale. Canadian companies are being talked with at the present time.



Cross section through the USA (Usinskoe Field) (From Meyerhoff and Meyer 1986)

- Komineft engineers now calculate that the field has only 3–4 more years production left of the "High Mobility Oil", after which steam stimulation will have to be used to produce the rest of the field. Fracturing of the zone would be considered, however, they don't have the equipment (another possible joint venture).
- 4 American built and 3 Canadian built steam generators have been purchased and pilot tests were tried with high temperature, high pressure steam (350°C @ 250 atm), however, the tubing, completions and general poor quality of the Soviet equipment led to major explosions. The tests were cancelled until better safety conditions could be set up. Also better training for the field staff is required to work with such high temperatures and pressures.
- New experiments are supposed to begin in 1990, however, they feel they need the help of Western experts in achieving safe, reliable projects. Again, AOSTRA may be able to assist in a technology exchange etc. to continue this project. Canadian suppliers of high temperature and high pressure pipe and completion equipment would also be welcome.

Yarega(Thermal Mining System)

Much has been written about the work done at Yarega with respect to thermal mining. Scientists from all over the world have been interested in this deposit because of its unique technology. The development of AOSTRA's Underground Test Facility (UTF) was based on the success of Yarega. Soviet scientists are deservedly proud of the technology developed at Yarega and are interested in promoting it to the rest of the world.

Our visit to Yarega Shaft #1 was directed by Mr. E. Gurov, Chief Geologist and Mr. S.M. Kuznetsov, Shaft Manager. They were super friendly and cooperative and allowed us to take pictures of the complex. We learned we were the fourth foreign group to tour the complex and the first allowed pictures. (Maurice Carrigy toured the complex with the first group in 1976).

The town of Yarega is located 35 km by road from UKHTA. The oil produced at Yarega is pipelined to a nearby railsiding and transported to the refinery at UKHTA. They have very little in the way of storage facilities at the plant site, thus, slow downs at the refineries directly affect their production.

This is the largest producing thermal mining complex in the world. In 1988 production was 503 thousand tonnes per year.

The deposit consists of 3 mines with a new mine presently under construction which should be ready in 1991. The production schedule for 1991 is:

Shaft	Production
1	350 k tonnes/yr
2	150 k tonnes/yr
3	250 k tonnes/yr
2B	305 k tonnes/yr (new shaft)
Total	1055 k tonnes/yr

The ultimate projection is 6 mines with an annual production of 1.66 million tonnes per year.

Since its origin in 1939, the development of production methods have changed several times.

1. Primary production from surface wells. Wells produced for 1–2 months and then ceased.
2. Development of the shaft with tunnels driven 20 meters above the oil zone. Wells were drilled from the tunnels and oil was produced by natural drive (UKHTA method). Production 1.5% of O.O.I.P.
3. Once the initial pressure was relieved, slopes were driven into the oil sand and slant wells drilled within its pay zone. Drainage mining through the wells due to natural reservoir energy (gravitation) occurred. Production of 2–4% O.O.I.P.
4. Introduction of thermal methods and thermal stimulation of the wells in the slant units occurred. Steam injection increased production significantly, enough to save the mines from closing. Production 40–50% of O.O.I.P.

Several methods were tested using thermal stimulation. These methods are described in the appendix, through diagrams supplied by Komineft and papers by Soviet experts.

Discussions and Observations

- The new mine 2B, will probably not be ready by 1991, however, it appears to be a major complex and more modern than the 3 existing mines.
- Komineft is in contact with Canadian companies to form a joint venture to develop heavy oil in Komi province. They appear to want to set up an agreement similar to what "Fracmaster" has with the people in Western Siberia.
- Their engineers indicated they need much more improved geophysical and geotechnical sensors for making underground measurements around the mines. At present they monitor only temperature and pressure and have nowhere near the sophistication of geotechnical tests done at U.T.F.
- They also need technology to break down the emulsions produced.
- Safety standards were better than I expected. Total air in the mine must be charged 4 times per hour with a minimum air speed of 1/4 meter per second for the mine.
- Pictures taken of the facilities at Shaft #1 are

provided in the Appendix. Unfortunately pictures from underground and at the shaft unit production face did not turn out as well as hoped.

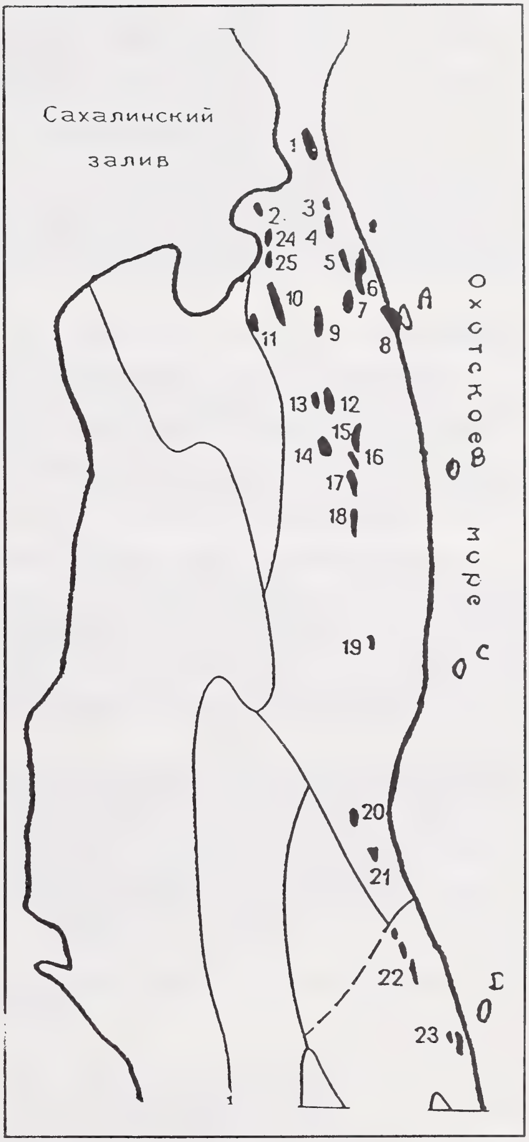
OKHA (SAKHALIN ISLAND)

SAKHALIN ISLAND

Visiting Sakhalin Island was a tremendous surprise as the area is considered a restricted zone within the U.S.S.R. We were the first Canadians to visit the oil fields of Okha and we were regarded as mysterious foreigners by the locals. With time our relations became better and we got along really well.

'Sakhalin Island is located in the Pacific Ocean, just north of Japan. Small scale oil production by the Japanese began there in 1921. As the events went, in 1905 Russia had lost the southern half of the island to Japan, as a result of the 1904–1905 Russo-Japanese War. In an attempt to improve their oil supply after World War I, and through World War II, the Japanese leased portions of the northern part of the island and oil production began on a small scale in 1921. The Soviet Government then began active exploration as well, and a checkerboard partition of fields between Japan and the U.S.S.R. took place. Sakhalineft was formed in 1927. The Soviets continued exploration and drilling and by 1935 their production on Sakhalin had surpassed Japanese production. At the end of World War II, Japan lost all of its concessions on North Sakhalin and also lost South Sakhalin.

The Soviet Union currently owns all of Sakhalin Island, and controls oil production there. However, the Soviets and the Japanese have participated in three joint ventures off the Coast of Sakhalin. In 1977, after a three year search, the Japanese Development Corporation found oil and gas. In addition, the Soviets and Japanese have recently entered into a $3.8 billion joint venture to build production platforms, a pipeline and a gas liquefaction plant to export gas from Sakhalin to Japan. An estimated 3 million tons of LNG will be shipped annually by tanker to Japan when the project goes ahead. A Soviet-Japanese consortium, Sakhalin Oil Development Corporation (Sedeco) was formed in 1975. It has been prospecting



Oil Deposits of Sakhalin Island

1. Kolendo; 2. Nekrasovskoe; 3. North Okha; 4. Okha; 5. Ekhabi; 6. East Ekhabi; 7. Tungor; 8. Odooptu; 9. Nelma-Erri; 10. Volchinka; 11. Shkhunnoe; 12. Sabo; 13. Krapivnenskoe; 14. Little Sabo; 15. Kydy Lanii; 16. West Sabo; 17. Mukhto; 18. Paromai; 19. Goromay; 20. East Dari; 21. Monghi; 22. Nogliki; 23. Nabie; 24. Tungusskoe; 25. Kenchevskoe.

Offshore Fields

A. Odooptu; B. Patunastohsk;
C. Chava; D. Loneska

successfully offshore, off the northeast coast of Sakhalin in the Sea of Okhotskoe. In the new Patunastohsk and Chava fields, it has established proven reserves of 86 million tonnes of crude oil and a 3.8 billion development plan calls for start up in 1990 (very tentative).

Several heavy oil fields have been found. The main heavy oil reserves are Okha, Katangli, Uiglekut, East Ekhabi and West Sabo." (Fane 1984).

2:A OKHA

The main purpose of our trip to Sakhalin Island was to observe the development of the Okha heavy oil field by thermal methods. Injection of steam followed by cold waterflood as a recovery technique was completely tested and successfully used in a commercial project at Okha.

We toured around the field and were given a geological assessment by the Chief Geologist and their production people. The field literally sits on the edge of the town with a large steam power plant located in the middle. The source of steam led to the development of the field using the steam stimulation-waterflood method.

Bokserman A.A. et al. definitive paper "Application of Heat Carriers upon Development of High-Viscous Heavy Oil Fields in the U.S.S.R." describes the results of the work done at Okha. The paper is included in the appendix for reference as the results are considered very good by the Soviets.

The following are selected notes taken during the talks at Okha.

Reserves	• 50 million tonnes Total
	• 20 million tonnes Recoverable
Geology	• 30–700 meters deep – avg. 100 meters
	• 60 meter payzone
	• Porosity 30%
	• Permeability 1 darcy
	• Weakly consolidated sandstone
	• Reservoir temperature 8°C
	• Oil gravity .930
	• Viscosity 150 cp @ 20°C 7200 cp @ 8°C

Results

- Project started in 1968, with steam injection followed by cold waterflood, injection of just water or air was not effective. This was one of the first thermal recovery test sites set up in the U.S.S.R.
- Using an 8 spot pattern (non symmetrical) they injected 20–50% (avg. 30%) of pore volume with super heated steam (Temp. 300–320°C) at a pressure of 20–28 atm). This was followed by injection of cold water. The total process gave a recovery of 60%.
- They treat each well differently, using various timeframes and steam injection amounts. Some wells are treated with chemical and others are not. A maximum of 3 steam cycles are used with some wells improving production up to 5 times.
- The method used and the amount of steam injected and timing is dictated by Moscow. They have developed computer models to set up the stimulation pattern. The field people just implement the instructions dictated by Moscow. Field conditions are quite primitive.
- Though the area is remote and the conditions are quite primitive the results obtained from the field were used to develop similar steam soak-waterflood projects in other areas of the U.S.S.R.
- Combustion (fireflood) was tried, the deposit is very shallow and low pressure air was injected. However, the project was stopped due to the production of pollutants which greatly affected the quality of life in its town.

Total oil production for Sakhalin Island is 300,000 tonnes per year, the oil is pipelined to Komsolmosk-Amur for refining.

2:B Other Projects

Several other pilot projects have been implemented at some of the other small fields on North Sakhalin, however, equipment was hard to get so often the projects were abandoned. These include:

Katangli	• Steam soak at 90 meters depth • Used steam generators (9 tonnes/hr @ 120 atm x 4 = 36 tonnes/hr) • Successful operation
East Ekhabi	• Steam injection to 600 meters • Unsuccessful due to explosions, pipes could not handle the high pressure steam • Well completions were not designed for high pressure steam
West Sabo	• Tried injection of steam at 1100 meters depth • 4 generators (9 tonnes/hr @ 120 atm) Total 36 tonnes/hr maximum • Unsuccessful due to lack of steam production, steam condensed at 800 meters

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2:C General Comments

- The cost of production of oil is 65 R/tonne, while the selling price is 48 R/tonne, therefore, there is a loss of 17 R per tonne of oil produced. The Ministry of Oil sets the price and the State covers all the costs of production. The production of oil at a loss means the Institute cannot raise money for reinvestment on even maintenance of their equipment and town. This is why the conditions here are so primitive. There remoteness and isolation plus the lack of money makes for a frustrating business environment. Transportation costs to Sakhalin are three times those of Siberia, so they are basically the last to receive anything from Moscow.
- The combination of oil seeps, asphalt lakes and just poor environmental standards has made for a very highly polluted oil field at Okha. In fact, their engineers were interested in the Taciuk Process as a technology to help clean up the area and produce products from the surface deposits. The remoteness and lack of funds, however, would probably negate this area as a candidate for the process.
- Surface transportation is a problem due to no paved roads and the very sandy soil. A small scale bitumen plant could produce bitumen for road building which would be very helpful for the town.

2:D Offshore Sakhalin

The highlight of our trip to Sakhalin Island and one of the highlights of our whole trip was the visit to the offshore jack up rig "Sakhalinskaya". Our hosts were most generous in arranging our flight to this rig.

The Sakhalinskaya, built in Finland, can drill in up to 100 meters of water with a capacity of 6500 meters. It has just come from drilling the Vietnam Sea. I would like to thank Nickolai Golubev of Sakhalinmorneftegaz for arranging our trip.

Discussions with our hosts indicated the following:

- Oil and gas have been found and proven, however, no offshore production has occurred.
- Both offshore and onshore wells angled under the ocean have been drilled (see pictures).
- Wells up to 12 km offshore in 45 meters of water.
- U.S.S.R. and Japan signed a Joint Venture Agreement in 1975 to explore for oil and gas in the Sea of Okhotskoe. The conditions of the Agreement stated that the Japanese would pay all costs until the consortium had found 100 million tonnes of oil and 100 billion m^3 of gas.
- Timeframe was 1975–1985, in 1984 the volumes needed to fulfill the Agreement were found.
- The U.S.S.R. wants to develop the deposits immediately to generate foreign capital, however, the Japanese have decided to sit on the oil and gas due to its proximity to home. The Russians have signed 90 different sets of agreements but talks are still in progress.
- The U.S.S.R. is now very frustrated because the Japanese will not develop the fields and only plan to develop them when prices and circumstances are suitable to them. The U.S.S.R. desperately needs hard currency now, so the members of the consortium are not on friendly terms. (This reminds me a bit of the joint venture that the Japanese had with Canadian coal companies in N.E.B.C.)

- All oil and gas found since 1984 belong to the U.S.S.R., however, their successes have been only in gas and not oil (U.S.S.R. now pays all costs).
- The present U.S.S.R. fleet on the East Coast consists of 5 jack up rigs, 40 supply ships, 1 oil recovery vessel (used at Valdez, Alaska), 10 service vessels and 1 heavy supply crane ship.
- The offshore fields found are
  1. Odooptu (Japan and U.S.S.R.)
     - anticlinal structure
     - 8 km offshore
     - oil and gas, depth 3000 meters
  2. Patunastohsk (Japan and U.S.S.R.)
     - anticlinal structure
     - oil, largest field (100 mil tonnes)
  3. Chava (U.S.S.R.)
     - gas and condensate field
  4. Loneska
     - large gas condensate field
     - 300 billion m^3 gas
     - 10 million tonnes condensate } Chava and Loneska

BUGULMA - TATARIA (MELEKESS)

TATARIA (Volga Urals)

The Volga-Urals region is rich in both heavy crude and bitumen. With the rise in interest in bitumen deposits in the U.S.S.R. the subsequent activity in the Melekess depression – Tatar Arch area of Tataria A.S.S.R. increased significantly.

Production of light and medium crude is also very prominent. During the period between 1955 and 1975, production of oil from the Volga-Ural region was up to 70% of the U.S.S.R. total. The most significant production is from the super giant "Romashkino" field in southern Tataria. This field was discovered in 1948 and is still in production. It was the first field to use waterflood stimulation from initial production, a procedure which became standard practice for the development of the giant fields in Western Siberia.

Our visit to Tataria was based in Bugulma, a town of 130 thousand people, 1500 km southwest of Moscow. Our hosts were VNIIneft (part of MTNK "Nefteodacha"). This group was created in 1986 and is responsible for all exploration and production of bitumen in Tataria. We also visited with Tatnipineft which is responsible for the development of oil and heavy oil in Tataria.

VNIIneft (All Union Scientific Oil and Gas Institute). This institute is responsible for the exploration and development of bitumen for MNTK. Their mandate "is to study recovery and refining and develop technology for production, transportation and upgrading of natural bitumen into a wide range of saleable products for world sale". Their goal in Tataria is to have a completely integrated institute responsible for exploration, production, transportation upgrading and refining. Tables indicate their planned scenarios.

The schedule set out has exploration and experimental work finished in 1995. The first pilot plant work is scheduled to start in 1991 on refining methods and a target of 1 million tonnes per year of synthetic oil production is targeted for the year 2000.

Their major challenge will be in the upgrading of bitumen to synthetic oil. Dr. Ferdman of MNTK has indicated that he has had preliminary discussions with AOSTRA concerning their mandate.

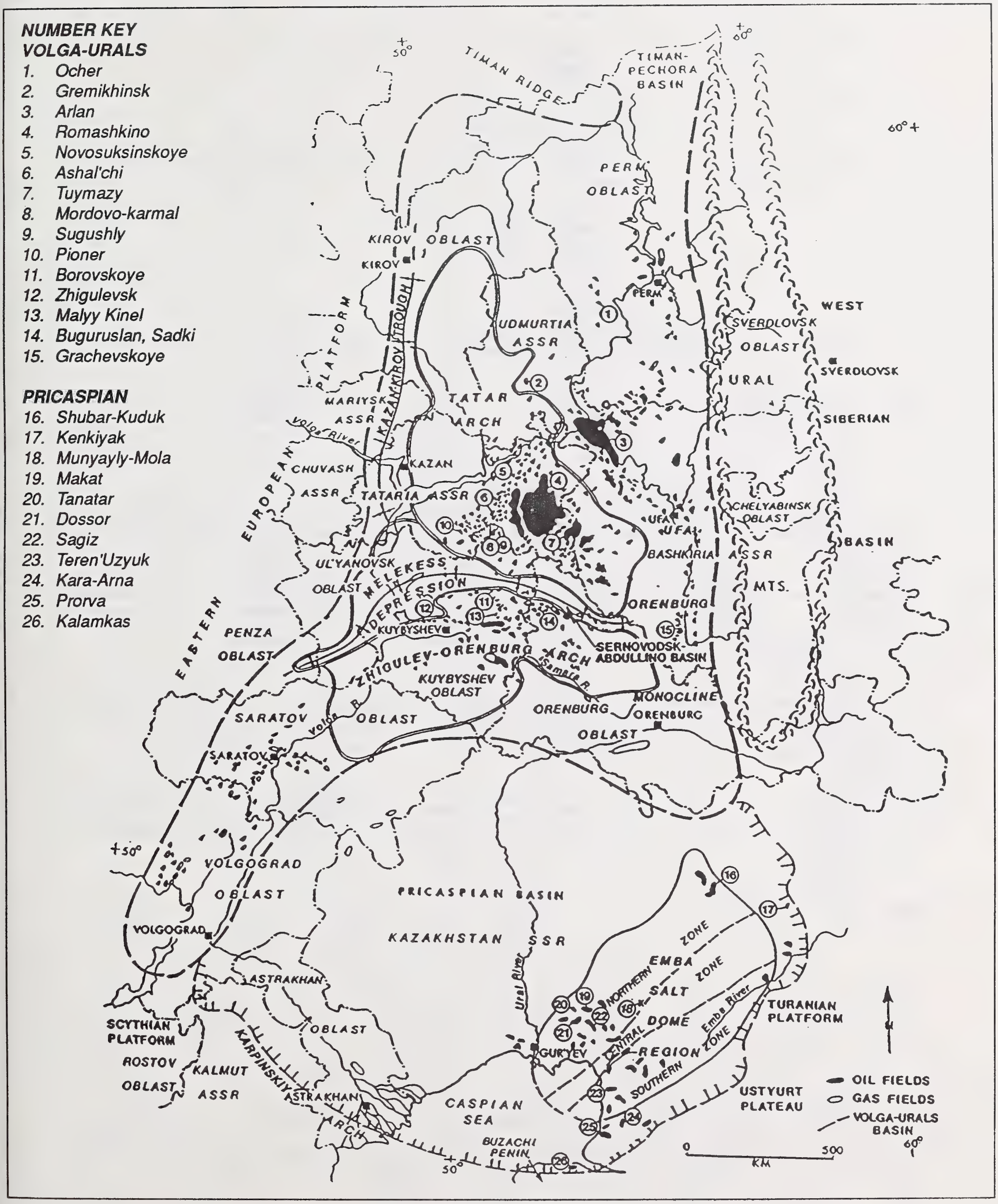
MNTK scientists recognize two types of bitumen:

1. Natural bitumen – which is produced as bitumen and either used as raw bitumen or upgraded into synthetic oil.
2. Bitumen and sand (kiree) – which is mined as a combined bitumen with sand product and used for road construction.

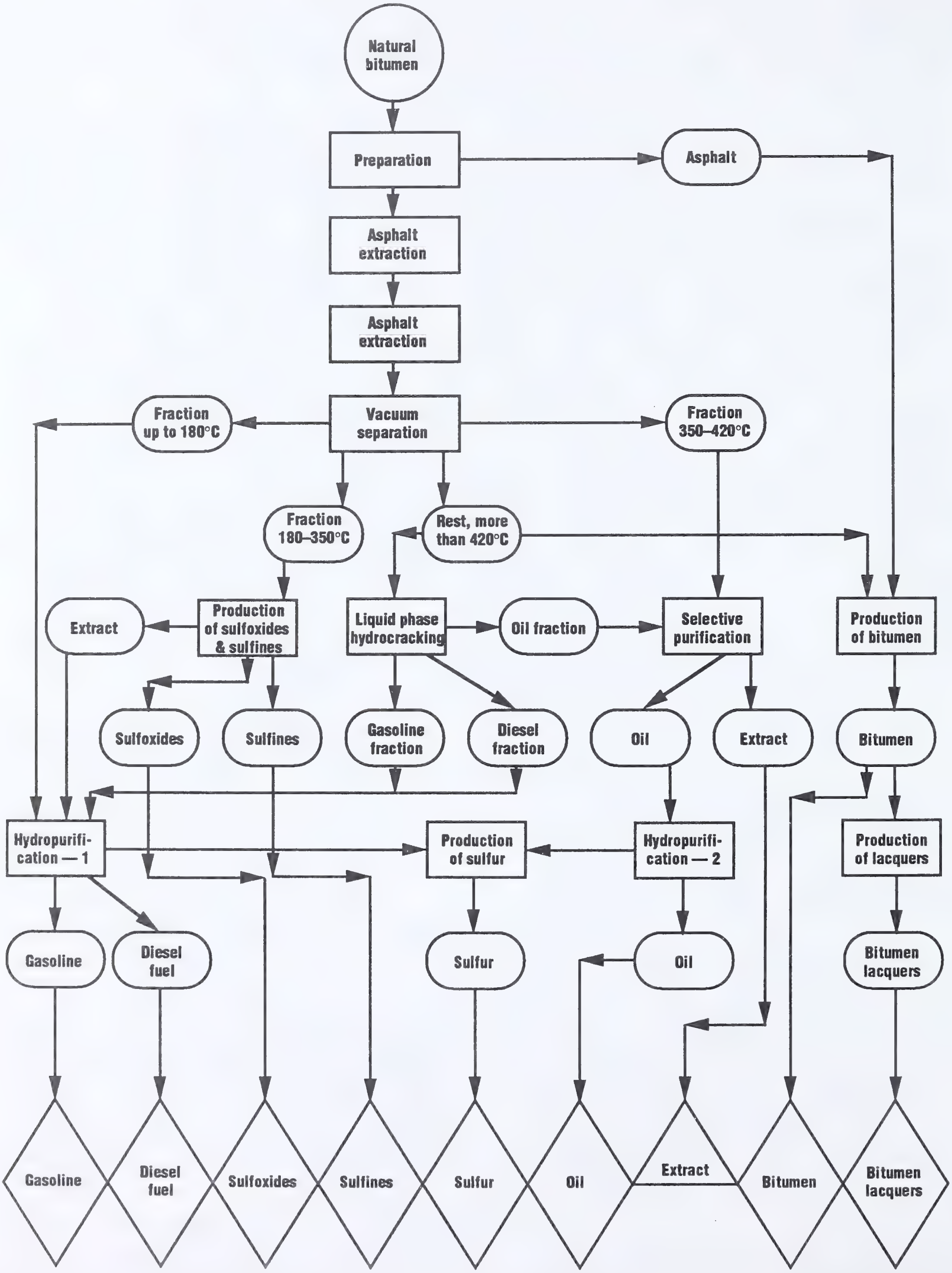
Natural bitumen can be produced by thermal methods in wells, open pit mining and shaft mining. Bitumen with sand (kiree) is produced by open pit mining. Reserves as indicated by MNTK for the U.S.S.R. are:

- Natural Bitumen (U.S.S.R.):
  – 20 billion tonnes (in place)
  – 12.7 billion tonnes (recoverable
- Bitumen with sand (U.S.S.R.)
  – 25–30 billion tonnes

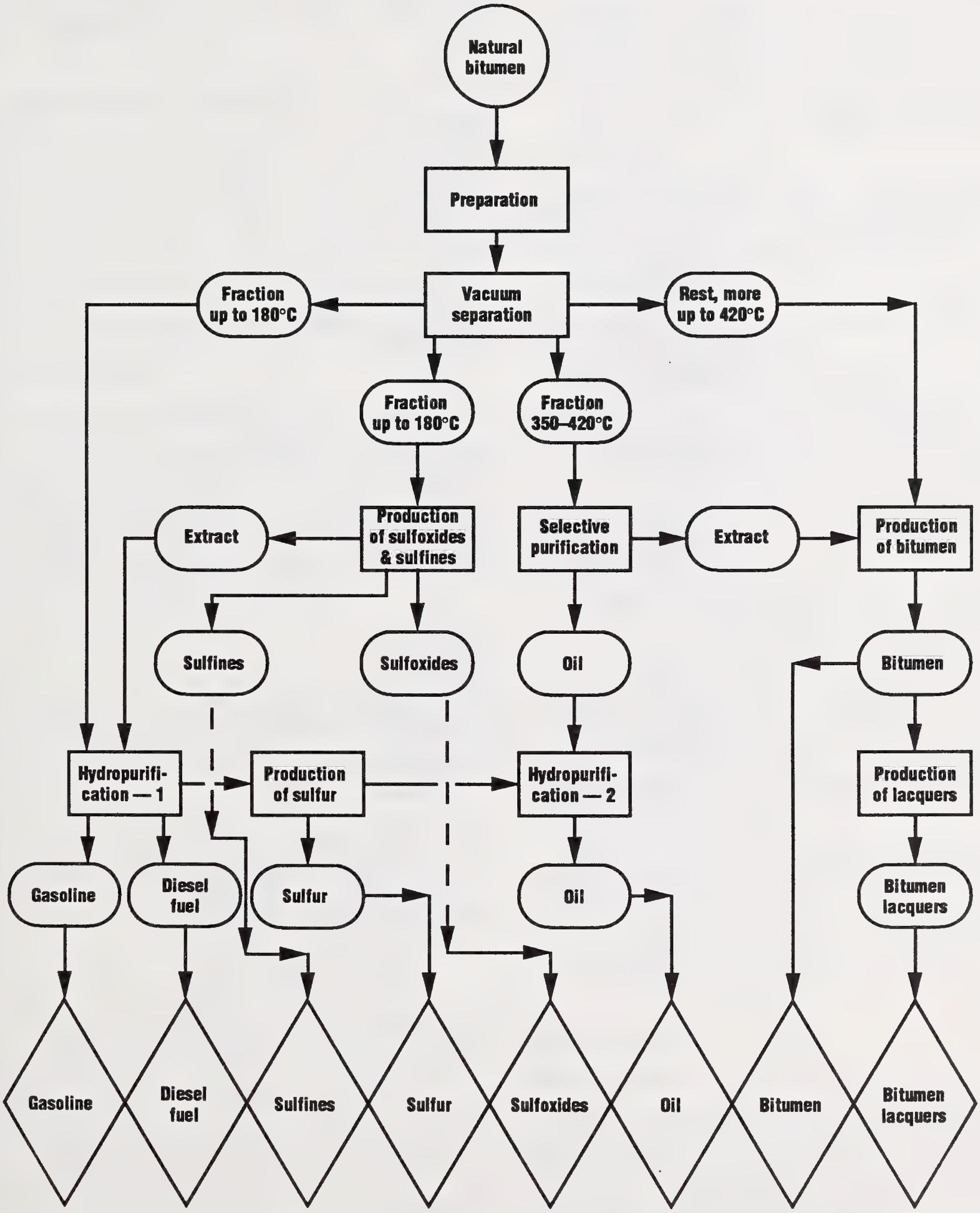
Reserves of both are found in Tataria.



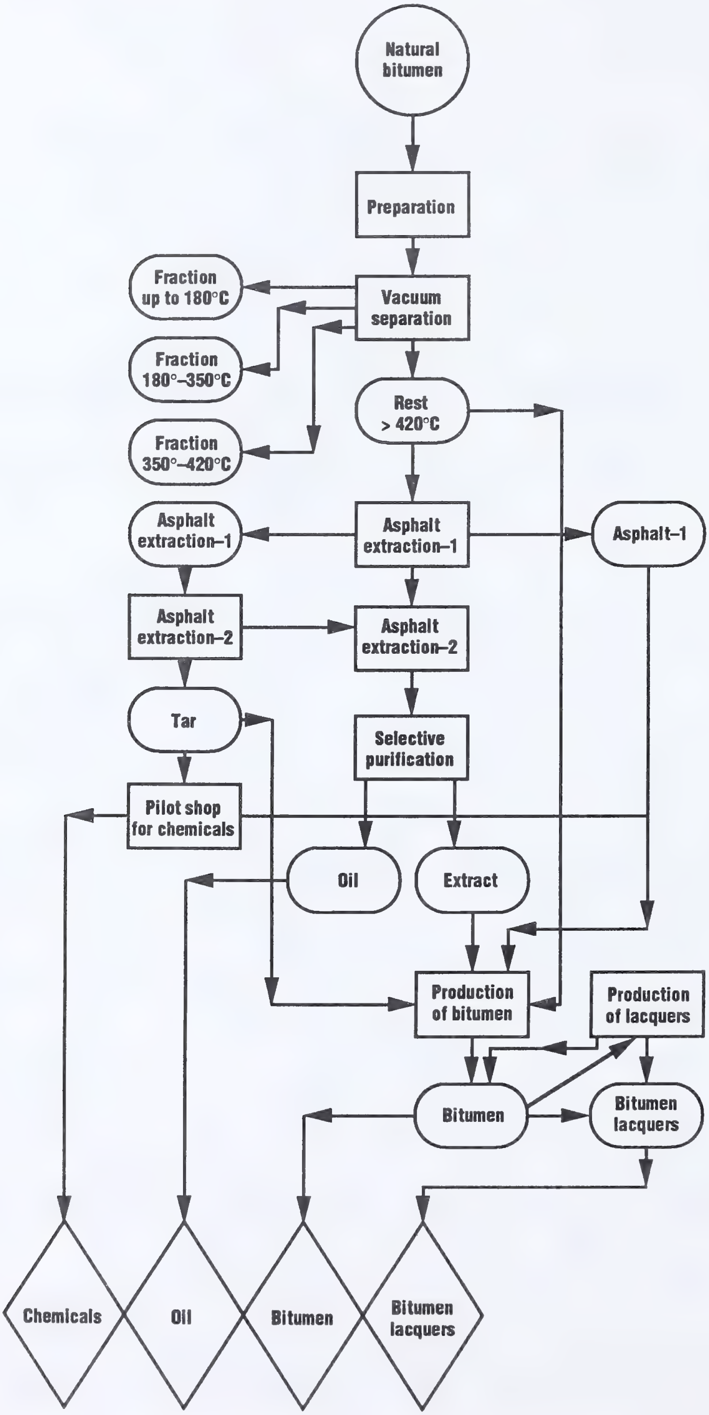
Heavy Oil and Bitumen Field of the Volga-Urals (Tataria) and Pri Caspian Basin (Northern Kazakhstan)



Technological Chart for Refining of Natural Bitumen – Method 1



Technological Chart for Refining of Natural Bitumen – Method 2



Technological Chart for Refining of Natural Bitumen – Method 3

Discussions held with scientists and staff of VNIIneft involved our introduction of AOSTRA and its work and their presentation of the work being done by their institute. The following are the highlights of our discussions.

Bitumen Development in Tataria

- Bitumen has been recognized and sporadically developed since the 1880's. Underground mining was done in the first half of the 20th Century and a bitumen refinery dating back to 1882 was visited by the authors. The Shuglinskoe deposit was worked until 1943 at which time war time circumstances dictated its closure. Pictures of the refinery and audit are found in the album.
- In 1970 the exploration for bitumen was again undertaken, the Mordovo-Karmal deposit was delineated and in 1978 the first pilot production was commenced. In 1986, MNTK commissioned a department to investigate only the bitumen deposits and they have been pursuing the goals mentioned earlier.

Reserves

Over 80 deposits of bitumen have been identified with in place resources of 7 billion tonnes. Ongoing exploration and evaluation is still in progress.

Twenty five deposits, representing a total of 82 million tonnes in place of which 25 million tonnes are deemed recoverable, have been identified to date.

Production

Cyclic steam stimulation and fireflood (combustion) methods have been tested and found successful. Combustion methods now produce 11,000 tonnes/yr of bitumen, however, engineers feel that steam stimulation and steamflood methods would be more applicable.

Comments on Production Experiences

- Steam drive and steam soak work very well.
- Their biggest problem is they don't have reliable steam generators to run efficient pilot projects. Their equipment is old and replacement parts are non-existent. They desperately want Western equipment to run their projects.
- Engineers agreed that steam methods are better but they use combustion because it is the only alternative, but combustion (fireflood) destroys too much of the useable bitumen as well as the heavy metal components of the bitumen.
- Control of the combustion front is often difficult, however, they have mastered both electrical and magnetic methods of mapping the firefront.
- Emulsions produced from combustion are often impossible to separate.

At the present time only raw bitumen and some bitumen and sand (kiree) is produced in Tataria. Their refinery which was originally built in 1882 is in the process of being upgraded to produce more products. The refinery presently produces 31 thousand tonnes per year of raw bitumen (pictures).

Production costs for bitumen are ≈ 100 rubles per tonne and the government controlled selling price is 60 rubles per tonne. This difference in cost is made up by the profits made by the refinery, however, to achieve any appreciable profit a new refinery complex is needed. Again, AOSTRA 's help was requested in the development of a refinery and in upgrading processes.

A small scale open pit mine was visited which produces bitumen with sand (kiree). The product is combined with raw bitumen and approximately 20 km of roads have been paved in the last few years. Further paving is planned in the future.

FIELD VISITS

Sugushlinsk

This deposit was first worked in 1903, with underground mining of bituminous sand occurring until 1943. One and a half km of tunnels were built during the period of 1920 – 1943, with the bituminous ore processed at the refinery at the mine mouth (picture). In 1978, engineers from Yarega evaluated the deposit for the shaft method of thermal mining, however, the costs were deemed to be too high.

Total oil in place is 120 million tonnes and future development by thermal methods is being considered. To date "At the Sugushlinsk deposit in Tataria, pilot-commercial injection of steam, sulphuric acid, solvents, in-situ combustion, reservoir stimulation by hydroabrasive material and high frequency electric currents have been used". (Dvorets et al.).

We toured outcrops and examined old audits, we also toured the bitumen refinery which is very antiquated. We also observed a small open pit mining operation which produces bitumen with sand (kiree). The site is 20 hectares, with ore at 4–5 meters depth, the bitumen content is 6.6% by wgt. Kiree is produced and mixed with raw bitumen to produce asphalt for paving. We travelled on a section of road which was paved by this process.

Modovo-Karmal

The Modovo-Karmal project is one of the largest combustion (fireflood) developments in a bitumen deposit in Tataria. Two projects are developed on the deposit. Discussions with Soviet engineers indicated the following:

- Start – 1978
- Two areas – North and South
- Total wells – 225
- Active wells – 57, they could have more, however, lack of equipment is a problem.
- Geological parameters
    - Lithology – Ufaian Sandstone
    - Porosity – 23%
    - Permeability – 43 md
    - Depth – 64–102 meters
    - Pressure – 4.4–5.2 atm
    - Oil – Mal
    - Density – .962 gm/cm^3
    - Viscosity – 3000 cp @ 8°C
    - Payzone – 11 meters
    - Formation temp– 7°C
    - Reserves – 4 million tonnes of oil in place
- System – 7 spot system
- Well spacing – 100 meter x 100 meters .86 ha
  – 50 meter x 50 meter

Each well is preheated for combustion using the portable steam-gas generator. The wells are allowed a period of free flow production before combustion is initiated. Steam stimulation is used to produce communication between the wells. The entire deposit is underlaid by bottom water, thus they use polymers and surfactants to seal off the water zone.

Observations

- Average speed of firefront – 0.056 m/day
- Original bitumen in place – 12.9%
- Bitumen in place after combustion – 4.3%
- Total recovery – 40% bitumen in place
- Firefront size – 1.2–4 meters
- Temperature at firefront – 600–700°C
- Rate of recovery of 0.0.1 P. of each unit – 8% per year at maximum
- Unit life – 8–10 years

  The design for the project anticipates 459 wells, 275 production wells, 114 injection wells and 70 observation and delineation wells.

  The experience gained from this project has led to important conclusions.

- High temperature at the firefront cause in situ refining of the bitumen thus many of the properties of the oil are lost, especially heavy metals.
- The produced emulsion is very hard to breakdown.
- The combustion process causes tremendous wear on equipment. They stated a pump jack normally lasts 400 days before repairs are required. Pump jacks on the combustion units last 40 to 50 days.
- They are mandated to use the combustion method, however, if they had a choice they would much rather use steam soak because it causes many less problems with equipment.

- Future plans call for a steam soak-wet combustion pilot, however, the lack of insulated piping has caused delays.

Our observation was that their engineers would much rather not use the combustion method, however, their lack of equipment for steam soak makes the combustion method their only alternative.

Tatnipineft (not affiliated with MNTK)

Tatnipineft founded in 1956 is one of the oldest oil and gas institutes in the U.S.S.R. The Institute handles all conventional oil and gas production in Tataria. It consists of three divisions, Geology-Development Division, Project Division and the Supply Division. Over 2500 people work there with their experts having worked all over the U.S.S.R. as well as in Iraq, Cuba and Algeria.

Our discussions were with the Geology and Development Division, we also visited pilot projects at Arhangelskoe and Noorlatskoe.

Tataria is considered a mature oil and gas province, 90% of the potential deposits are developed. The area has been well drilled and studied, forty-six deposits are under development including the super-giant Romashkino field, the second largest in the U.S.S.R. with reserves upward of 20 billion barrels.

The Soviet waterflood system of production was developed in Tataria at Romashkino. This method is now the standard in the U.S.S.R.

Combustion methods (fireflood) was tested at Unit #24 Romashkino, upper horizon and also at Arhangelskoe and Noorlatskoe.

Unit #24 Romashkino — Upper Layer

- 9 units, 5 spot configuration
- Depth – 1000 meters
- Carbonate reservoir, permeability 650 md
- Oil viscosity 20 cp
- Payzone thickness 3.8 meters
- Duration 1979 – 1988 (9 years), Project now being terminated
- Equipment – 6 compressors @ 12 m^3/min air @ 1 atm.

Ignition for combustion was by electrical heater (24 k watts). The original flow resulted in a "Fountain" but flow tapered off with time. Results were 35% of O.O.I.P. was recovered, the project was terminated when 85% of the produced fluid was water. A total of 65,000 tonnes of additional oil was recovered through the combustion project. A ratio of 1 tonne of oil per 1000 m^3 of air was achieved. Major problems were corrosion and control of the firefront Also there was a significant water zone in the formation which acted as a pirate for the injected air. The air preferentially flowed into the water zone and thus was not available for combustion. Their conclusion was the test was successful, however, there were too many problems with the combustion methods.

Arhangelskoe Field

- Depth 1000 meters
- Sandstone Fm
- Payzone 6–7 meters
- Permeability 200 md
- Oil viscosity 40–45 cp
- Formation temp 24°C

This project was started in 1987 with a 7 spot configuration, wells are 300 meters apart. Plans are to develop a new unit every two months. They presently have 5 units with 23 producing wells in operation. A ratio of 1 tonne of oil per 1500 – 2000 m^3 air injected is occurring. Some units have increased production 5 to 6 times with the combustion method, however, the total overall increase in production is quoted to be 10–15%. Their biggest problem is separation of the emulsions produced.

Noorlatskoe Field

This field was toured by the authors. This is currently a priority project using wet combustion:

- Depth 1200 – 1300 meters
- Sandstone reservoir
- 15 million tonnes reserves
- Oil viscosity 144 cp
    - Sulphur – 3.2%
    - Asphaltites – 10–12%
    - Oils – 28–30%

- Oil density – 930–980 gm/cm^3
- Permeability – 200 md
- Formation temp. – 24°C

Primary production was 1–3 tonnes per day, per well. From 1983–1987 conventional waterflood was used and production increased 3 to 4 times. In 1987 combustion methods were tried. Three 7 spot units with well spacing of 300 meters were set up. Six compressors of 12 m/min of air are used, water injection is 26 m^3/hr. Results indicated an average increase in production of 2 to 3 times with some wells increasing up to 10 times the waterflood flow rate. A ratio of 1 tonne oil per 1500 m^3 air was calculated, however, they expect the ratio to drop to 1 tonne oil per 500 m^3 air in the future. They are encouraged with the results and plan further expansion, especially in areas of high viscosity oil (7100 cp) where the combustion methods were deemed to work best. They quoted a 30% O.O.I.P. recovery rate with waterflood and a 54% O.O.I.P. recovery rate with wet combustion. In conclusion the combustion project is a success and they plan to continue the project for 5–6 years. They then want to try hot water injection (water @ 150°C) and measure the results.

KIEV

Kiev is capital of the Ukrainian Republic and one of the biggest industrial, scientific and cultural centers of the Soviet Union. Kiev's population runs to more than two and half million. It is also one of the oldest cities, with 1500 years of history. The good public transportation and the beauty of Kiev made our stay there very enjoyable.

Kiev branch of MNTK "Nefteotdacha"

The Ukraine has only one small heavy oil deposit "Borislava", and because of that, MNTK "Nefteotdacha" deals with bitumen and heavy oil deposits in other soviet republics: Belorussia, Eastern Russia, as well as in Cuba, Africa etc.

The U.S.S.R. has a wide network of different pipelines for transportation of gas, oil, chemical and petrochemical products. Today 4 billion tonnes of oil and oil products are transported to the petrochemical industry in Ufa, but by 2000 it is expected to increase transport facilities to handle 25 billion tonnes. Many of the products are toxic, fire hazardous and explosive and are causing problems with their reliability and safety during transport. Kiev MNTK specialists have expressed concern about all aspects of pipeline design and construction. For example, a CO_2 project at an oil field 150 km from Toliatti was cancelled because they had about 100 CO_2 pipeline explosions in 4 years.

The big pipeline explosion near Ufa (Bashkiria) caused a passenger train disaster where more than 1000 people burned to death. Very costly accidents on pipelines in Western Siberia at the Almentievskaia refinery (Romashkino oil field in Tataria) brought to light many problems haunting the Soviet oil and gas industry. (Sloppy workmanship, inadequate design , outdated quality control equipment, etc.)

Dr. A. Sverdlov, the head of the Laboratory on transportation and injection of aggressive agents, talked to us about his planned trip to the U.S.A. and Alberta and asked for assistance in setting up meetings with E.R.C.B. and pipeline industry. The goal of his visit is evaluation of the state-of-the-art pipelines in regard to the mentioned problems including design, regulations and standards, inspection procedures, technological processes and technical means of starting pipeline operation, methods and technical means for pipeline diagnosis, computerized control systems, etc. This trip is scheduled for January 1990.

Ukrgiproniineft (State Research and Project Institute of Oil Industry)

This institute is not affiliated with MNTK "Nefteotdacha". It conducts operations in Ukraine, Belorussia, Eastern Russia, as well as foreign operations in Cuba, Africa and others. Institute researchers and engineers can develop a complete project of oil field operation including primary, secondary and tertiary recovery methods..

In addition to the traditional E.O.R. methods, new secondary-tertiary recovery methods have been implemented: They include:

- **Pilot Steam Injection:** Tested on shallow fields with light 14 cp oil. This method gave good results for very old (50-70 years old) fields, but there are few remaining shallow fields left. For deeper fields, the institute has designed special insulated pipes,

- **Combustion — Fireflood:** Used for very light oil (1.5 cp) after waterflood has been applied. Scientists consider results as tentative but they are not optimistic because of many problems with fireflood such as corrosion, coke deposition, unreliable firefront, danger of explosions etc.
- **Chemical Methods:** Combination of surfactant and alkaline chemicals, hot water injection for oil with high paraffin content, injection of gas-water-gas and gas-water cycle flood.
- **Injection of Light Gases:** Ethane-Butane-Propane is tested for secondary-tertiary recovery.

The majority of oil deposits researched by the institute lie at 1800–5500 meters. A tested oil field contains pure oil, oil & gas and oil condensate. They consist mainly of SST deposits with permeability of 0.01 millidarcy to 1–2 darcy.

Pure CO_2 Injection Projects

Injection of pure CO_2 is considered a very promising technology for oil recovery. The institute has tried two projects:

- Use of liquidized CO_2. Armand Hammer had donated the German unit for liquidizing CO_2 with a capacity of 2 million tonnes of gas per year. An oil field 150 km from Toliatti (city on Volga) was chosen as an experimental site. The project lasted four years and gave good results, but was cancelled because of pipeline explosions — up to 100 in 4 years. Total expenditure was 70 million Rubles.
- Use of CO_2 from a process of Nitrogen amalgamation of gas of Perm (Ural) area. The source of CO_2 is situated 100 km from OLKHOV oil field — site of operation. Pressure of the CO_2 pipeline is 100 atm with a buster station at the oil field at 250 atm. Projected injection pressure is 250 atm into 24 wells. Pipeline is constructed from Japanese 219 mm pipes, tubing and fittings. The operation has not started yet because fittings do not hold CO_2 (contrary to Japanese specification). Planned mode of operation is the CO_2–Water cycling process.

Projected increase of oil recovery at 10–14% was achieved at the oil fields where operation was conducted.

KRASNODAR

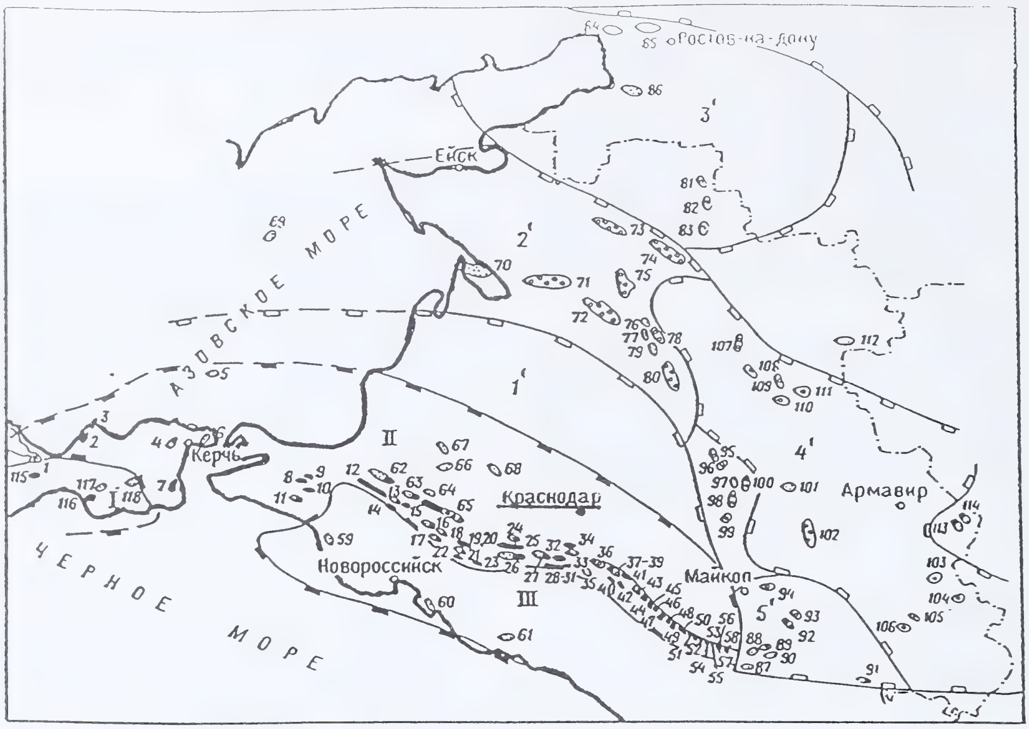
Krasnodar, a city of almost 1 million people is located 1500 km southwest of Moscow near the shores of the Black Sea. The oilfields around Krasnodar are some of the oldest in the U.S.S.R. dating back to the 1860's. The first thermal recovery methods (fireflood) were tried at the Neftegorsk field in 1933. This work was done by SoyuztermNeft (our host) who are responsible for overseeing all enhanced recovery projects on oil (not bitumen) in the U.S.S.R. Soyuzterm Neft is one of the scientific and research organizations of MNTK.

SoyuztermNeft

They are the oldest organization working on thermal methods in the U.S.S.R. and basically oversee all thermal enhancement projects. We reviewed some of their projects in Komi, Tartaria and Krasnodar. Their mandate encompasses research, pilot projects, field tests and manufacturing of equipment for thermal methods.

Work on thermal methods first started in 1924, with lab scale research on the in situ gasification of coal. The success of this work led two scientists to apply these concepts to heavy oil deposits. The first in situ thermal method (fireflood) was tried on the Neftegorsk field in 1933. The work was considered very successful and was even visited by Stalin prior to World War II. With the commencement of the war the work was halted but pilot work started again in the early 1960's. Since 1964, thirty thousand tonnes of oil have been produced from the tiny Neftegorsk deposit. The first steam soak (cyclic steam stimulation) was implemented at the Zybza field, commencing in 1964. The success of the Zybza project led to further research and implementation of thermal methods throughout the U.S.S.R. SoyuztermNeft is now responsible for two large semi commercial projects at Karajanbas in Kazakhstan and Usinskoe in Komi. They also operate a full scale commercial project at Kenkiyak in Kazakhstan.

Their work to date has indicated that each field



Oil and Gas Deposits of Krasnodar Region, South Rostov and South-East Crimea Regions

1. South Sivashskoe; 2. Semenovskoe, 3. Aktashskoe; 4. Molobabchikskoe; 5. North Kerchenskoe; 6. Vorzovskoe; 7. Priozernoe; 8. Beliy Khutor; 9. Strelchanskoe; 10. Suvorovo-Cherkeeskoe; 11. Blagoveshchenskoe; 12. Dzhighinskoe; 13. West Adagumskoe; 14. Adagumskoe; 15. Keslerovskoe; 16. Kudakovo-Kievskoe; 17. Krymskoe; 18. North Krymskoe; 19. Abino-Ukranian; 20. Abinskoe; 21. Ukrainian; 22. Sheptalskoe; 23. Kholmskoe; 24. North Akhtyrskoe; 25. Levkinskoe; 26. Akhtyrsko-Bugundyroskoe; 27. Zybza-Glubokii Yar; 28. South Karskoe; 29. East Ilskoe; 30. Ilskaia Valley; 31. Novoilskoe; 32. Azovskoe; 33. East Severskoe; 34. Severskoe-West Afipskoe; 35. Stavropolskoe; 36. Novodmitrievskoe; 37. Kaluzhskoe; 38. Severskoe-South; 39. Svobodnenskoe; 40. Chibiiskoe; 41. Ilichskoe; 42. Staro Kaluzhskoe; 43. Dyshskoe; 44. Kluchevoe; 45. Abuzinskoe; 46. Apchasskoe; 47. Kutaisskoe; 48. Kura-Tsitse; 49. Wurokoe-Asphaltovoe; 50. Kabardinskoe; 51. Khadyzhenskoe; 52. North Khadyzhenskoe; 53. Khadyzneskaia Ploshchadka; 54. Voskovas Mountain; 55. Neftianskoe; 56. Neftegorskoe; 57. Pavlova Mountain; 58. Khopry; 59. Vitiazevsko-Anapskoe; 60. Doobskoe; 61. Praskoveiskoe; 62. Kurchanskoe; 63. Zapadno-Anastasievskoe; 64. North Anastasievskoe; 65. Anastasievsko-Troutskoe; 66. Sdlavianskoe; 67. Frunzenskoe; 68. Krashoarmeiskoe; 69. Morskoe; 70. Beisugskoe; 71. Kanevsko-Lebiazhie; 72. Chelbasskoe; 73. Starominskoe; 74. Leningradskoe; 75. Krylovskoe; 76. South Leninodarskoe; 77. Novoserdukovskoe; 78. Serdukovskoe; 79. South Serdukovskoe; 80. Berezanskoe; 81. North Kushchevskoe; 82. Kushchevskoe; 83. Ekaterinovskoe; 84. Siniavskoe; 85. Rostovskoe; 86. Azovskoe; 87. Samurskoe; 88. Shirvanskoe; 89. Maikopskoe; 90. Red Daghestan; 91. Barakaevskoe; 92. Tulskoe; 93. Noreth Tulskoe; 94. Maikopskoe; 95. North Ladozhskoe; 96. Ust;-labanskoe; 97. Ladozhskoe; 98. Nekrasovskoe; 99. Velikoe; 100. Ubileinoe; 101. Temipgoelskoe; 102. Koshchekhablskoe; 103. South Sovetskoe; 104. Besskorbnenskoe; 105. West Voznesenskoe; 106. Kuznetsovskoe; 107. Alekseevskoe; 108. Malorossiiskoe; 109. Mitrofanovskoe; 110. Lovlinskoe; 111. Kavkazkoe; 112. Illiinskoe; 113. Ubezhenskoe; 114. Nikolaevskoe; 115. Vladislovskoe; 116. Moshkavevskoe; 117. Kuibyshevskoe; 118. Fontanovskoe

is unique and therefore different technologies are suited for different fields. They now emphasize the importance of geology and depositional characterization in outlining the best methods. The book **"Thermal Methods of Petroleum Production" by Baibokov, N.K. and Garushev, A.R.**, is considered the definitive publication on thermal methods in the U.S.S.R. Dr. Garushev was kind enough to present copies of this book to us and we are now ordering an English copy for the AOSTRA data bank.

General comments by SoyuztermNeft:

- Their annual budget is 15 million rubles and annual production is 1.5 million tonnes of oil per year through enhanced oil recovery methods.
- Manufacturing of good quality equipment has become a high priority for them. They now manufacture and sell some of the best equipment in the U.S.S.R. including steam-gas generators, insulated tubing, packers, completion equipment, etc.
- They have permission for a joint venture and are looking for a partner to participate in a joint venture in the production of oil using thermal methods. They mentioned a joint venture signed by Fracmaster of Canada whereby extra production from wells using Fracmaster technology will be allocated to the joint venture for sale on the world market at international price. This agreement was signed in July 1989.
- SoyuztermNeft is very interested in discussions with AOSTRA and other Canadian firms interested in setting up some type of arrangement. They want to sell the product for hard currency to insure a viable return for all parties and want to use their share to buy Western products to upgrade their own manufactured products.
- They have been fighting the bureaucracy for years to develop their manufacturing plant. Now that it is a success, many people in the Ministry are jealous of their achievements and want to control them. They are a very aggressive and progressive group and I was particularly impressed with their people and organization. I feel they are an excellent contact for AOSTRA to cultivate in the U.S.S.R.
- Again, concerns about the environment were expressed. Environmental considerations are now being incorporated into their work.
- The regional disputes between A.S.S.R.'s in the U.S.S.R. has led to a lack of refining capacity for their crude oil. Dr. Garushev expressed a sincere desire to discuss with AOSTRA, or any interested Canadian groups, the construction of a new state of the art refinery. This organization would eventually like to be a fully integrated group with research, production and refinery of petroleum products.

"Neftetermash" - Manufacturing Plant

A significant accomplishment for SoyuztermNeft is the manufacturing plant (Neftetermash) at Chernomorsk about 50 km from Krasnodar. The plant was developed because equipment from Soviet factories was very hard to get or was of very poor quality. They now design and manufacture, to their own specifications, a variety of equipment used for thermal stimulation recovery.

The main benefits of manufacturing their own equipment was the reduction of initial investment, access to modification and cost and quality control. They now produce:

- Steam-gas generators and accessories;
- Steam generators;
- Insulated tubing and production pipe;
- Packers, reimers, downhole completion units;
- Separators;
- Surface well completion units.

Brochures with descriptions and specifications of their equipment are contained in the Appendix.

The steam-gas generator was of particular interest. We observed it in the field in Tartaria and in Krasnodar.

Steam-Gas Generator

- Two models, UMP.G–10/16 Dragon with a steam output of 1.25–10 ton/hr and the UMP–6/16 "Geyzer" with a steam output of 3–6 ton/hr.
- Completely portable units, 1 production unit, 1 service vehicle, 2 compressors. It is run by a

three man crew.

- The units have been tested in the U.S.S.R., Hungary and Romania.
- One unit has been sold to the United States.
- The deepest test to date is 1050 meters, however, they plan to test it at 1500 meters in the Usinskoe field in Komi.
- The unit has been tested at –50°C in northern conditions.
- Results have indicated flow levels of 10 times that of primary production after steam cycles.

Continuing design modification is being done on these units and two new models are being built. They are now experimenting with oil, kerosene, chemicals, etc. being injected with the steam to improve performance.

Talks with Western companies to participate in a joint venture are wanted. They need Western made control systems, computers and better compressors to produce what they feel are "export quality" products.

We suggested they might want to demonstrate their units in Canada and show them at the Oil Show. Their response was very enthusiastic and a letter of invitation has since been sent by the Department of Alberta Economic Development and Trade (November 28, 1989). If they do come to Canada, they have offered to demonstrate the unit for AOSTRA and any interested companies. Coordination of a demonstration by AOSTRA would be appreciated if and when they come.

Field Visits

Several oil fields were visited including Neftegorsk, Zybza and Akhtirsko-Bugundiskoe. These are now exhausted fields in which experimental work on thermal methods has been done. At the time of observation, some small scale steam soak experiments were being done at Zybza, the others were shut down due to the fact their steam generators were broken down. As is often the case in most areas we visited, the thermal test facilities were not working due to obsolete equipment or lack of parts.

Zybza (Glubokii Zone) Deep Zone

- Depth 700 meters – Temp 30–40°C
- Payzone – 0–150 meters (pinch out carbonate)
- Lithology – Well fractured carbonate
  Oil viscosity – 250 cp @ 50°C

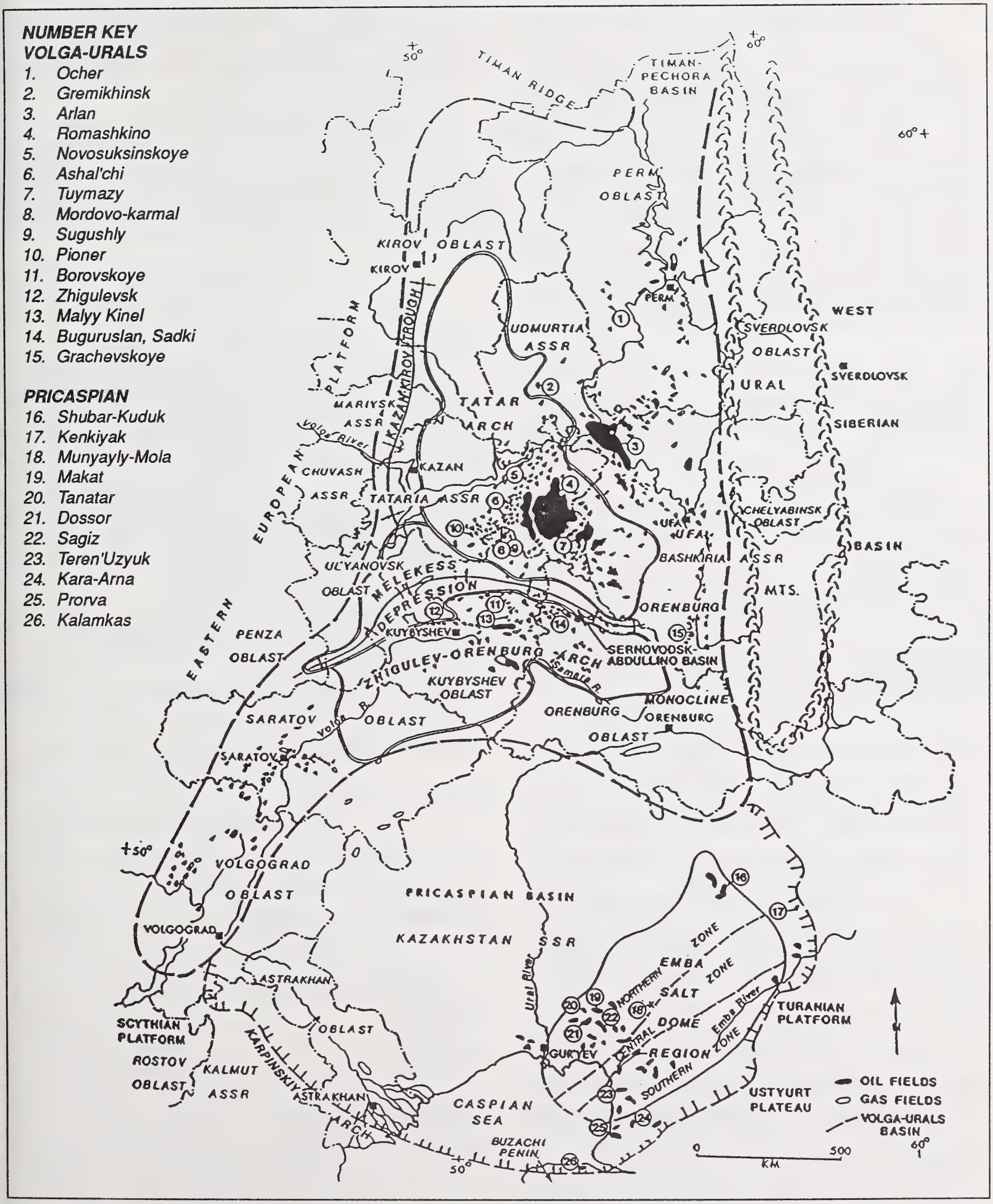
The field started production in 1946 and thermal stimulation was introduced in 1965. Thermal stimulation ceased in 1988 due to lack of reliable equipment. Results during the 23 year period indicated an additional 270 thousand tonnes of oil was produced with an overall steam to oil ratio of 5:1. Attached is the paper "High Viscosity Oil Recovery from Carbonate Reservoirs by Thermal Methods" by Antoniadi, D.G. et al. This paper describes in more detail the results obtained from the work on the Zybza field and others.

Also visited was the Akhtirsko-Bugundiskoe field. It was first developed in 1949 and thermal methods were implemented in 1985. This field is in a Paleocene sandstone at depth of 400 meters. Formation porosity is 20–30% and permeability 1 darcy, the oil has a density of .94 gm/cm^3 with viscosity of 2100 cp @ 20%. Results of steam soak in this sandstone horizon were quite promising and further work may be considered for the future. Pictures, both ours and some provided by our hosts, are included in the Appendix. Of note is the age of the facilities.

Comments

SoyuztermNeft was very impressive in their presentation. This organization basically handles all thermal recovery projects for heavy oil and is a natural contact for AOSTRA.

Their sense of direction and drive, especially in the construction of their own manufacturing facilities, was impressive. They definitely want to have discussions with AOSTRA concerning technology exchanges and areas of mutual research and development. The design, production and demonstration of the steam-gas generator which now gives them a monopoly on this technology in the U.S.S.R. was very interesting. It would be nice to see them demonstrate their unit in Canada in conjunction with AOSTRA.



Heavy Oil and Bitumen Field of the Volga-Urals (Tataria) and Pri Caspian Basin (Northern Kazakhstan)

ALMA-ATA, KAZAKHSTAN

Alma-Ata, the capital of Kazakhstan is 3,000 km south of Moscow. It is truly one of the most beautiful cities in the U.S.S.R., combining six different cultures into a city of outstanding historical and modern development. We visited with two organizations, MNTK's division, where we discussed the exploration and development of bitumen and heavy oil deposits in Kazakhstan and the Ministry of Highways (Dortechnika) for Kazakhstan where we reviewed the development of highways and the recent use of "kiree" (bitumen with sand) as a road building material.

MNTK Discussions

We were given a review of the work on heavy oil and bitumen in Kazakhstan. As most of their work is in the Northwestern part of the A.S.S.R., there were no field visits.

Kazakhstan is the second largest A.S.S.R. in the Soviet Union, it has the second largest reserve of oil and gas and ranks third in oil production. Their immediate goal is to improve oil production to rank second in the U.S.S.R. It is also one of the richest areas of the U.S.S.R. and the climate for business and combined technical cooperation appears to be very favorable.

Heavy Oil and Bitumen in Kazakhstan

The first studies were implemented in 1970, however, no serious work was done due to the abundance of light and medium crude. It was not deemed necessary to appropriate funds and people for heavy oil and bitumen studies. In 1975 more work was done, mainly in the field of geological identification of heavy oil and bitumen deposits. This work was based on the successes of Canadian and American companies in developing these types of deposits.

In 1983 serious work began on resource categorization of heavy oil and bitumen. They set up a 10 year program with the following directions:

- New evaluation of existing fields to determine the heavy oil and bitumen content (earlier these reserves were ignored);
- New exploration for near surface heavy oil and bitumen deposits;
- Re-evaluation of exhausted oil fields, some which have up to 60% of the heavy oil left. New production can be induced using thermal and other enhanced oil recovery methods.

The resource categorization will be complete in 3–5 years. Of particular note is the results of re-evaluation of exhausted and producing fields to determine heavy oil and bitumen content. Results have indicated the existence of many layered deposits i.e.

Depth ↓
Bitumen
Heavy Oil
Medium and Light Oil

Originally the bitumen and heavy oil factions were ignored, but they have been now found to contain very significant reserves of oil amenable to enhanced recovery methods. In some cases, as much as 60% of the original oil in place.

Results to date have been the identification of over 130 deposits at depths of 0–150 meters in Western Kazakhstan. Work is now being done on deposits to 600 meters and more.

Western Kazakhstan Deposits to 150 Meters

Number – 130+
Size – usually 20–70 million tonnes but up to 100 million tonnes
Lithology – Terrigenous -sandstone-shale interbedded rocks
Structure – Simple monoclines and small arches, with minor fault offsets
Oil – Density 0.96–99 gm/cm^3
Viscosity > 10,000 cp
Saturation – Minimum – 3 1/2–4% oil by wgt.
Maximum – 15% oil by wgt.
Average – 7–10% oil by wgt.
Thickness – 5—70 meters, average 24 meters
Reserves – To date – 200 million tonnes
Projected – 1 billion tonnes
Production – None to date, however, they are very interested in developing these deposits. They are very interested in acquiring AOSTRA technology, expertise and equipment for pilot projects.

The largest field identified to date is 'Mortuk' near Guryev in the Emba oil fields of the Pri Caspian Basin. This field was discussed by their staff geologists.

Mortuk Deposit

Location – 8 km from Kenkiyak

Reserves – 100 million tonnes @ > 4% bitumen by wgt.

Geology – 4 horizons to 300 meters

Composition – Oils – 25 - 60%

Malthas and asphaltenes - 40–75%

Density .96–.99 gm/cm^3

Viscosity 10,000 cp

Grade – Average 9–10% bitumen by wgt.

Production – Proposed 800 K – 1 million tonnes/yr

Open pit mining to 40 meters, then in situ development with wells using thermal methods. Preliminary study of underground shaft method is now being done.

Their plan for heavy oil-bitumen development dictates commercial production by 1995. They want to produce 3–3.5 million tonnes/yr of heavy oil - bitumen.

Areas in which they are interested in cooperation with AOSTRA are:

- Developing a surface deposit i.e. mine technology and development
- Low temperature extraction of bitumen and methods of upgrading to a synthetic crude.
- Shaft mining - they want to discuss with AOSTRA , their technology at UTF.
- AOSTRA technology for development of bitumen and heavy oil at depths which surface mining is impractical.
- Resource categorization methods used by AOSTRA for heavy oil and bitumen. That is, methods for calculating reserves and resources, oil in place, cut off grades, mine planning, computer mapping etc. They indicated that the methods they use are for conventional crude (light) deposits and these procedures have a tendency to produce large errors.

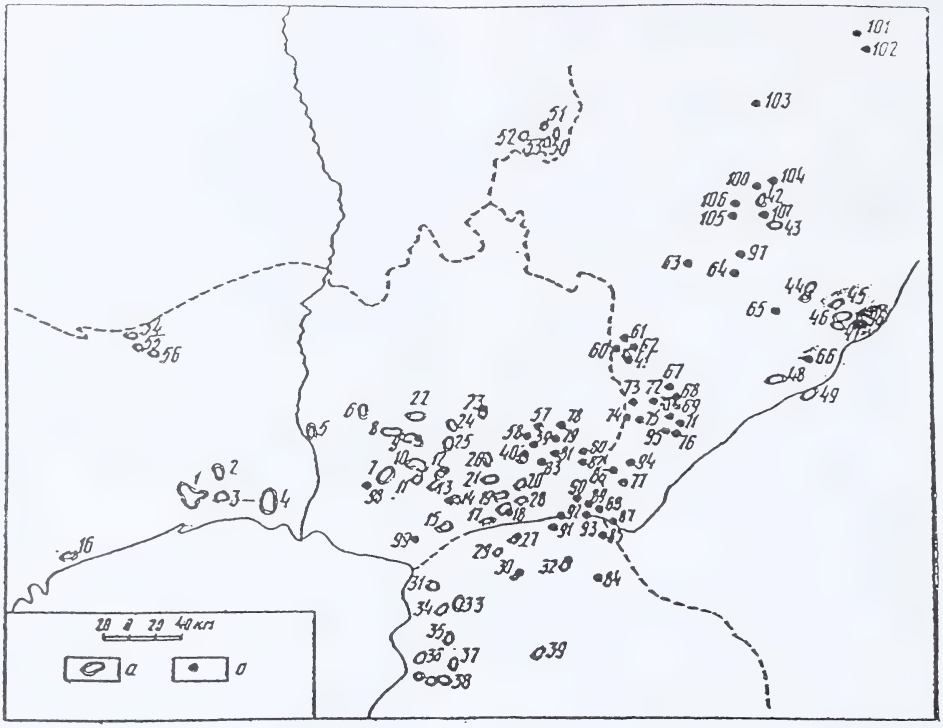
Department of Highways (Dortechnika)

Our stay in Alma-Ata was coordinated by Dortechnika as they have a very large department in the city. Several of their people have been in Calgary and Edmonton in December 1988, so they had a good knowledge of AOSTRA.

They have developed the use of bitumen with sand ("kiree") for road construction. The method has proven very successful and they plan to use it extensively in the future. Their major interest in AOSTRA is to enter into a joint venture (or any type of venture) to generate foreign currency. They are also interested in buying road making equipment from Alberta suppliers and would also be interested in AOSTRA expertise in developing processes for separating bitumen from the mined ore and development and construction of small scale plants for bitumen

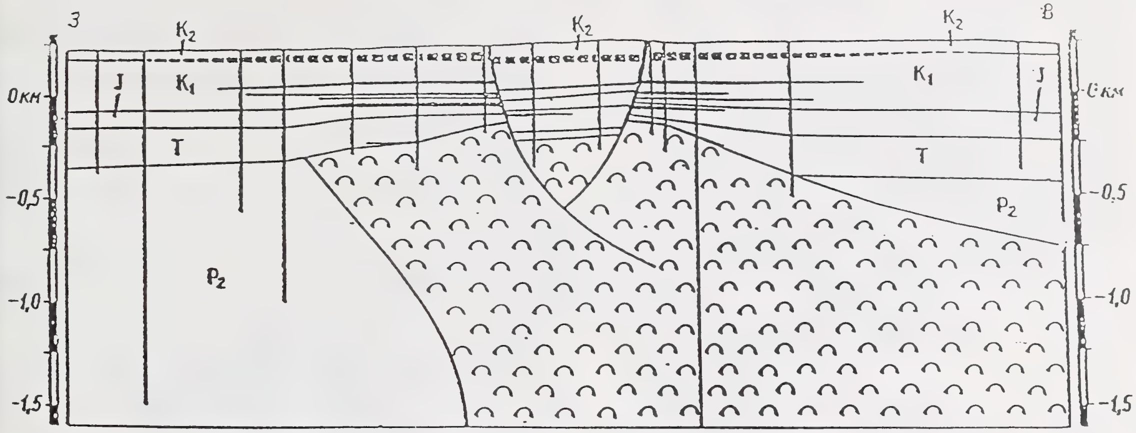
Talks with Dortechnika

- There are 94,000 kilometers of paved roads in Kazakhstan.
- Dortechnika has a budget of 1 billion rubles per year and employs 92,000 people.
- In Alma-Ata there are 1,500 people, 1,200 of which are professionals. They are responsible for research and development into new methods, materials and equipment for road construction. They also supervise the factories for production of equipment.
- Dortechnika recently signed a large contract with Mongolia to build roads and plan to utilize the use of "kiree" where possible. They are also negotiating with several Comecom and third world countries for road construction.
- "Kiree" was developed because they had no local source of bitumen. They could not get reliable supplies of bitumen from outside sources, so they developed a system to use "kiree". They feel that using Kiree is cheaper than conventional methods over the long run.
- In 1988, 2,000,000 tonnes of kiree was mined and construction of 2,000 km of roads was completed.
- Cost for transporting the Kiree was economical up to 100 km by rail.
- They want to develop methods for extracting



Scheme of the Spatial Distribution of Fields, Pools and Natural Outcrops of Bitumens in the Southeastern Part of the Caspian Sea

a — oil fields and pools: 1 — Zhanatalap; 2 — Gran'; 3 — Martyshi; 4 — Kamyshitovyy; 5 — Baklanyy; 6 — Karatal; 7 — Iskine; 8 — Tanatar; 9 — Dossor; 10 — Tyulegen'; 11 — Baychunas; 12 — Bisbulyuk; 13 — Tentyaksor; 14 — Akatkul'; 15 — Korsak; 16 — Oktyabr'skaya; 17 — Ayrankul'; 18 — Kzylkala; 19 — Antykul'; 20 — Kamyskul'; 21 — Narmundunak; 22 — Zhengel'dy; 23 — Zholdybay; 24 — Makat; 25 — Sagiz; 26 — Koshkar; 27 — Kulsary; 28 — Dyuseke; 29 Koschagyl; 30 — Tyulyus; 31 — West Teren'uzyuk; 32 — Munayli; 33 — Karaton; 34 — Tazhigali; 35 — Karaarna; 36 — Morskoy; 37 — Aktyube; 38 — Prorva; 39 — Burankul'; 40 — Bekbeke; 41 — Kopa; 42 — Dzhaksymay; 43 — Shubarkuduk; 44 — Karaganda; 45 — Kumsay; 46 — Kenkiyak; 47 — Kokzhide; 48 — Akzhar; 49 — Karatyube; 50 — Chingiz; 51 — Telsu; 52 — Beket; 53 — Kubasay; 54 — Bolganmola; 55 — Auketaychagul; 56 — Karagayskaya; b — natural bitumen outcrops: 9 — Dossor; 12 — Bisbulyuk; 14 — Akatkul'; 18 — Kzylkala; 23 — Zholdybay; 27 — Kulsary; 30 — Tyulyus; 32 — Munayli; 40 — Bekbeke; 41 — Kopa; 44 — Karaganda; 53 — Dzhalgaz; 58 — Kutartas; 59 — Alambay; 60 — Zhdalya; 61 — Munaylisay; 62 — Levite; 63 — Sorkudduk; 64 — Karaulkel'sy; 65 — Ittassay; 66 — Kursay; 67 — Saryk; 68 — Murzaadyr; 69 — Dongeleksor; 70 — Koskul'; 71 — Aktakyr; 72 — Kzyldzhar; 73 — Kiyaktysay; 74 — Uzunkul'; 75 — Zhdamankoblandy; 76 — Tersakkan; 77 — Alashakazgan; 78 — Togusenushak; 79 — Dzhilankaban; 80 — Kirasay; 81 — Akchiy; 82 — Karamurat; 83 — Imankara; 84 — Ul'kentyube; 85 — Isekdzhal; 86 — Chubantam; 87 — Uyaly; 88 — Araltyube; 89 — Bakachi; 90 — Dzhusalysay; 91 — Takyrbulak; 92 — Kul'dzhan; 93 — Kaskyrbulak; 94 — Shilisay; 95 — Ak-cheka (Kayraktykyl'); 96 — Mortuk; 97 — Kumbaur; 98 — Abzhel'; 99 — Zhdarchik; 100 — Dzhamanagach; 101 — Petropavlovskaya; 102 — Aleksandrovskaya; 103 — Karakhobda; 104 — Kalmyk-Karagan; 105— Alaty-Karasu; 106 — Taskemir; 107 — Keykebas.



Geological profile of Mortuk structure, ratio of vertical to horizontal scale is 1:2.

At present there is no production of bitumen in Kazakhstan, therefore, an agreement with AOSTRA for technology licensing or consulting would put AOSTRA in at the ground floor.

the bitumen from the sand economically.

- They only want bitumen and are not interested in upgrading unless a profitable product can be produced for export sale.
- The ministry has numerous deposits throughout Kazakhstan with the main deposit a Kulsary south of the City of Guryev.
- A 4 volume publication outlining their research and development has been sent to AOSTRA.

Conclusions

Dortechnika is a very well run and prosperous ministry and would appear to be an ideal joint venture partner for AOSTRA or any Alberta company which is interested in doing business with the U.S.S.R. They have permission from Moscow to enter into a joint venture, thus they will not have to get approvals from Moscow. This will obviously make setting up agreements much easier and faster.

BAKU - AZERBAIJAN S.S.R.

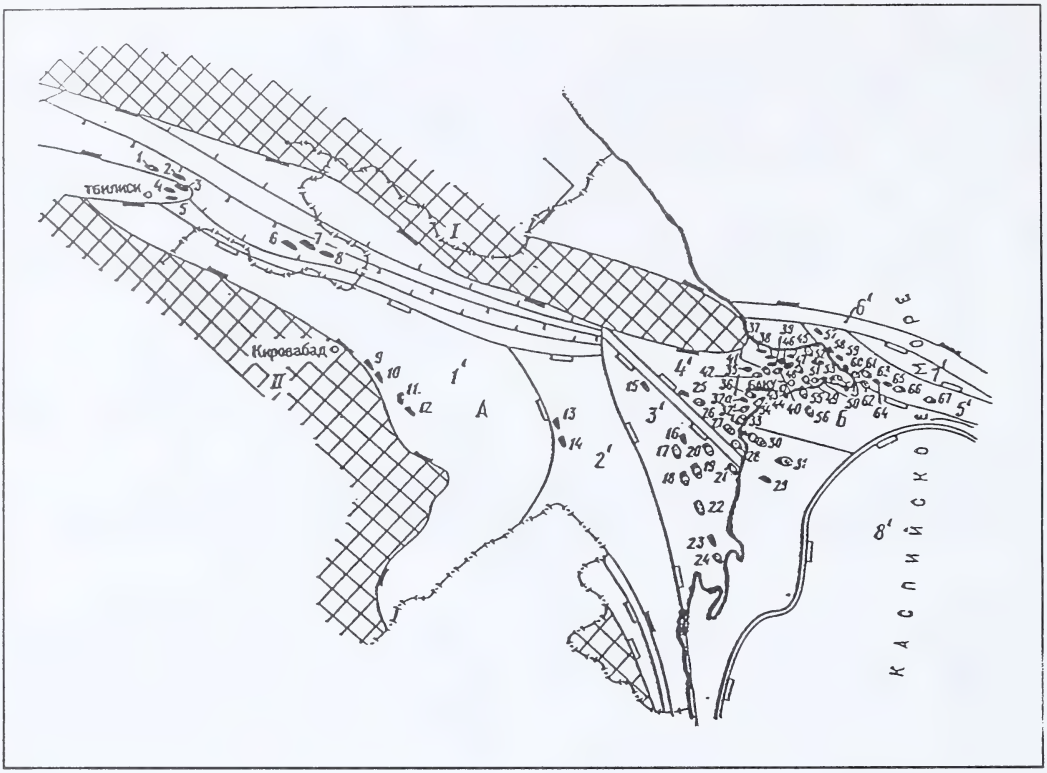
The final stop on our agenda was Baku, the capital city of Azerbaijan. Baku is 2000 km south of Moscow, on the west shore of the Caspian Sea. It is an ancient city not only in age but in oil production. Once part of the Silk-Route, Baku was once home to Marco Polo, and parts of the old city can still be seen. Baku is also the home of the first oil production in the U.S.S.R. The first wells go back to the 1870's and continuous production has occurred since. Azerbaijan has produced over 1 billion tonnes of oil during its history and the future continues to look bright with the discoveries of oil in the Caspian Sea (offshore).

We were hosted by Azneft the principle oil and gas producer in Azerbaijan. Our program included discussions with several groups as well as tours of the oil fields and bitumen deposits on Apsheron Peninsula and visiting an offshore production vessel in the Caspian Sea. We also toured a modern factory which produces offshore production platforms.

We were also very pleased to meet with Dr. M.D. Abasov, a member of the Academy of Science in the U.S.S.R. and Chairman of the Academy on problems of oil and gas deposit development.

Bitumen Deposits on the Apsheron Peninsula

The bitumen deposits of the Apsheron Peninsula have yielded asphalt and kir for many centuries. The development of the oil industry in the U.S.S.R. started at Baku. Wells were drilled as far back as 1871 when the oil was produced by buckets and rags.



Oil and Gas Deposits of Eastern Part of Georgia and Azerbajan

Oil and Gas areas: A. Kobystano-Kurinskaia; B. Apsherono-Pribalkhanskaia; Deposits: 1. Norio; 2. Satskhenici; 3. Samgori-Patardzeyli; 4. South Cap of Samgory; 5. Teleti; 6. Taribani; 7. Mivzaani; 8. Patava-Shiraki; 9. Kazanbulag; 10. Adzhidere; 11. Naftalan; 12. Mirbashir; 13. Zardob; 14. Muradkhanly; 15. Kalamadyn; 16. Mishovdag; 17. Kiurovdag; 18. Karabagly; 19. Kiursanglia; 20. Kalmas; 21. Pirsagat; 22. durovdag; 23. Milly; 24. Neftechala; 25. East Adzhively; 26. Umbaki; 27. Duvahnyi-Susha; 28. Dashghil-Delianiz; 29. Qarasu; 30. Sangachaly-more-Duvannyi-more-Bulla Islands; 31. Bulla-more; 32. Kergez-Kyzyltepe; 32a. Shongar; 33. Karadag; 34. Lokbatan-Puta-Kushkhana; 35. Kapaeibat; 36. Qezdek; 37. Masazyr; 38. Sianshor; 39. Bynagady; 40. Chakhnaglar; 41. Sulutepe; 42. Shabandag-Shubany-Yasamalskas Valley-Atashkia; 43. bibieibat; 44. Bukhta Iliicha; 45. Kiurdakhany; 46. Kirmaku; 47. Balakhany-Sabunchi-Ramany; 48. Surakhany; 49. Karachukhur; 50. Zykh; 51. Qousany; 52. Buzovny-mashtaghi; 53. Kala; 54. Zyria; 55. Meschannyi-more; 56. Bakhar; 57. Banka Apsheronskaia; 58. Banka Darvina; 59. Artema Island; 60. Qiurgiany-more; 61. Uzhnoe; 62. Uzhnoe-2; 63. zhiloi Island; 64. Azi-Aslanova; 65. Qriazevaia Sopka; 66. Neftianye Kamni; 67. In name of 28 April.

The presence of bitumen and heavy oil on the Apsheron Peninsula is well documented. It occurs in small isolated pockets related to mud volcanoes, exposed surface strata and fractures. Mud volcanoes are prominent both on and offshore, with kir deposits known to be associated with at least 20 mud volcanoes. The kir occurs as matrix in the extruded muds and sands and as pore filling in erupted blocks of middle Pliocene age. The bitumen content of saturated beds ranges from 0–30%.

Also prominent on Apsheron are very shallow pools of heavy oil in the shallow blocks of the Pliocene producing zone.

The surface seeps and the shallow heavy oil pools are of interest for developing by open-pit and shaft methods. The deposits at Kirmaku and Balakhany-Sabunchi-Ramany were the two discussed during our talks.

Goldberg 1981 states :

> "The oil pools of Azerbaydzhan which crop out at the surface or lie at shallow depth are subdivided into three types on the basis of the extent of oil saturation. The first group includes pools (oil content up to 60 kg/m^3) from which no oil flows under the influence of gravity; the second (oil content from 60 kg/m^3 to 100 kg/m^3) drains freely even when small prospect pits are dry; and the third (oil content more than 100 kg/m^3) drains still more intensively than the second (see pictures). The strata dips steeply and are traced from the surface to depths of 500 m or more. The total effective thickness of the strata varies from 10 to 300 meters."

Azneft has identified over 30 deposits of bitumen on Apsheron Peninsula. Documented reserves are 38.4 million tonnes of bitumen and 38.9 million tonnes of heavy oil.

Kirmaku Field

The field occurs on a topographic high 12 km northeast of the city of Baku. Old pits and outcrop were investigated by the authors, photos graphically indicate the flowing nature of the bitumen in the highly saturated beds.

Goldberg (198)1 states:

> "It is controlled by the 100 meter high rise of the same name, which is the morphologically expressed crest of an asymmetrical anticline. Oil bearing sands of the KC suite crop out at the surface, interbedded with clays and clayey silstones. The effective thickness of the oil bearing strata reaches 270–30 meters. The density of the oil is 0.930–0.940 g/cm^3, the viscosity of near surface samples 61 mpa, boiling point 180°C. The oil contains 73.65% oils, 15.42% tars, and 3.33% asphaltenes."

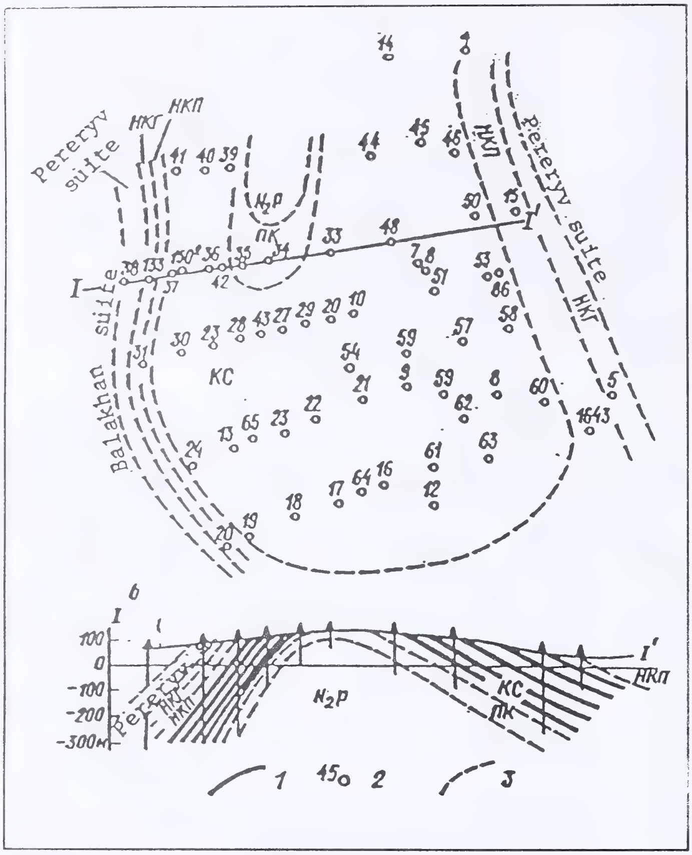
Solid and viscous bitumens are confined to Early Caspian and recent deposits overlying the producing strata. They form kirized bands (Yashkir) which are persistent along strike and contain from 7.26 to 10.20 wt % bitumen (density 1.08–1.11 g/cm^3), and also occur in the form of lenses, pockets and inclusions of pure asphaltite with a density of 1.12–1.15 g/cm^3 and softening temperature of 135–158°C.

Discussions with Azneft geologists indicated the reserves at Kirmaku are 16.634 million tonnes of bitumen with a further 17.050 million tonnes of heavy oil at depth. The strata is semi consolidated sand and bitumen with porosity of 20%, permeability of 200–250 m.d. and a temperature gradient of 1° per 32 meters. Azneft has developed a bench scale process of bitumen extraction and claim that the washed separated sand can be used to produce glass.

The Kirmaku deposit, because of its reserves, location and oil content, is considered the most feasible for development by Azneft. We have recently learned that a European company "Roevin Deutschland GmbH" and Azneft have recently signed a Joint Venture Agreement to develop this site. AOSTRA has been contacted for discussions to determine their interest in licensing their technology or working on a consultant basis on the project.

Balakhany-Sabunchi-Ramany

The second deposit discussed and visited by the authors was the Balakhany-Sabunchi-Ramany field. It is a shallow, medium-heavy crude field which underlies the village of Balakhany.



The Kirmaku Deposit.
After S.G. Narirov (1977).

a — geologic map, b — section I—I.
1 — oil-bearing strata; 2 — exploratory boreholes;
3 — stratigraphic contacts.

Goldberg (1981) states:

"It is controlled by an asymmetrical anticline eroded in the crest to the lower part of the upper section of the producing sequence. In the upper section of that sequence the strata lie at a depth of 80-365 meters, in the lower, at 440–910 meters. The oil pools are of stratiform-anticlinal type, cut by faults into individual blocks. In the upper section of the producing sequence they are confined to the nose of the fold. The density of the oil varies in the sections of the field, from 0.886 to 0.915–0.926, the viscosity from 45 to 152 mpa's. Bitumen shows are related to the Bog-Boga mud volcano, which occupies the highest hypsometric position in the field. In connection with repeated flows of oil from the vent of the mud volcano, up to five kir flows consisting of viscous bituminous rock ("Yashkir") are observed in the thickness of recent sediments."

Discussions with Azneft indicate that a large reserve of oil is located beneath the town of Balakhany. In the late 70's they did a study using the shaft method to develop this deposit. Engineers found the method would be economic, therefore, in 1975 two shafts were started. They used the methods and technology developed at Yarega, however, they encountered problems. The Yarega technology was basically the same as used in underground coal development. The consolidated nature of the rock at Yarega makes this method feasible but the nature of the rock at Balakhany was much different, therefore, many problems occurred.

The shafts were under development from 1975 to 1984. The project was shut down in 1984 due to lack of funds, however, the major reasons for the shut down were three fold:

1. The nature of the sediments were such that the methods used at Yarega did not work. Machines got stuck and all efforts to continue failed.
2. The presence of near surface gas caused many problems, which made numerous changes in plan occur.
3. Continuous delays for modifications, power lines, ventilation etc. occurred. Planning was poor.

The project is presently on hold and will be reviewed after 1990. Their engineers believe the project is feasible, however, they need to buy or access Western made large diameter boring machines. (They know of German equipment which can cut a 9 meter diameter hole and can reach 1,000 meters.) They are interested in AOSTRA experience and technology used at UTF and may want to discuss possible joint ventures or technology exchanges if the project is revised.

Comments

The two deposits described above should be of particular interest to AOSTRA. The surface bitumen (kir) deposits appear to be ideally suited for the Taciuk Process. Az-Neft scientists mentioned they would like to set up 2 refineries or upgraders of 500 tonnes per day to process these surface deposits. The Balakhany et al. deposit would be a candidate for AOSTRA to license or sell the technology they have developed at UTF.

Meeting with Dr. M.T. Abasov

We were privileged to meet with Dr. M.T. Abasov a member of the Academy of Sciences and Chairman of the Scientific Council of Academy of Sciences of the U.S.S.R. on problems of oil and gas deposits development. He is also a member of the Azerbaijan S.S.R. Academy of Sciences and a member of the Soviet Congress.

We discussed our observations, and in particular, mentioned how AOSTRA technology, especially the Taciuk Process and UTF experience would be helpful to the Baku area.

Oil production has occurred on the Apsheron Peninsula for over 100 years and the subsequent environmental problems left by waste oil and surface contamination, is enormous.

The whole area is filled with oil impregnated soil and sand as well as lagoons and lakes which are filled with oil. There are predictions that the oil slug in the Caspian Sea around the Baku area contains millions of tonnes of oil.

The Soviet Government is now very concerned with the environment and is making a concerted effort to clean up their country. The Taciuk Process would appear to be an ideal candidate for cleaning up the contaminated soils, muds and slugs around the Baku area. It could also be used in the development of the surface kir deposits as mentioned earlier. Dr. Abasov was quite interested in the AOSTRA technology and indicated he would like to contact AOSTRA.

Upon our return, we found out that Dr. Abasov had contacted AOSTRA. A joint venture group which wants to develop the bitumen deposits had also contacted AOSTRA for discussions.

From our observations, this opportunity would seem to offer the best near term opportunity for AOSTRA to license their technology to the U.S.S.R.

Offshore Production

We were able to discuss offshore drilling and production with the Azneft people, as well as visiting a production trestle at the Nurimanov field.

Azerbaijan has produced over 1 billion tonnes of oil and present reserves on the Apsheron Peninsula and under the Caspian Sea are projected at 2–3 billion tonnes.

Presently there are 300 production platforms in the Caspian Sea, most producing in waters up to 30 meters deep. The soviets have developed a trestle system to connect platforms in shallow water. Platforms are connected by causeways far out into the sea. In fact, they have built a town in the middle of the sea to house workers and supplies.

Current offshore production is 10 million tonnes per year of oil and 13 billion m^3 per year of gas.

Projected production for the year 2000 is 15 million tonnes per year of oil. Wells reach 6000 meters in depth.

New discoveries have been plentiful and and exploration is continuing. 250 prospective structures have been identified. The latest discovery is the April 28 field in the deep Caspian. The drilling occurred in 100–150 meters of water, the deposit is multizone (12–16 zones) at a depth of 3000–4500 meters. Reserves have been calculated at 500–600 billion barrels.

All offshore exploration and production is the responsibility of Azneft, based in Baku. They are also responsible for offshore drilling in the Kazakhstan and the Crimean sectors of the Caspian Sea.

The deepest drilling is now in 123 meters of water, however, platforms are now being built to handle 150 meter depth. The first platform was built to last 25 years, however, it is still producing after 40 years. New platforms are designed to last 50 years.

At present there are 250 exhausted platforms not in use. They have a problem reclaiming them, they cannot use explosives because of the environmental aspects related to the fish. Their law dictates a maximum charge of 600 grams can be used, which is not nearly enough to break up the platforms. They are looking for "new ideas" and possible Western help in reclaiming these platforms.

Other areas where problems occur are in undersea pipelines, especially joints (they need flexible joints and connectors which can connect flexible to rigid pipe).

They need insulation methods to protect from paraffin condensation in the lines because of its cold water. Other areas where Western technology would be welcomed is in undersea pipeline monitoring i.e. underwater television cameras, corrosion control, electronic protection of the pipe, etc.

Shelf Proektstroi - Bego - Factory

This plant is one of the most modern in the U.S.S.R. it was completed in 1988 to build offshore drilling and production platforms. The factory was built for the Ministry of Oil by the French Company ETPN, using French and German technology and equipment. It is a high tech operation which manufactures pipe and builds platforms to very strict specifications. The factory processes 60,000 tonnes of metal per year to produce pipe. The manufactured pipe is from 530–2000 mm in diameter with wall thicknesses up to 90 mm. From the pipe they build the offshore platforms, this being a complete turn-key operation. They even install the platforms at sea (pictures). The present platforms are being built for 150 meter deep seas, and eventually they will produce platforms for seas of 200 meters. 4,000 people work at the plant.

We were very impressed with the hi-tech nature of this plant, in fact, it was the most modern facility we observed in the U.S.S.R.

RESEARCH

VANADIUM, NICKEL AND OTHER METALS IN NATURAL BITUMENS AND HEAVY OILS

Since 1981, some extensive work has been done in the U.S.S.R. on determining concentrations of metals especially vanadium and nickel in heavy oils and bitumen. Byproduct recovery of metals can substantially reduce the cost of other products

Vanadium and Nickel Content in the Oils of Selected Fields

Area/Field Host Rock	Age of oil g/cm³	Density of oil	Sulfur %	V (V_2O_5) g/t	Ni g/t
Komi					
Yarega	Devonian	0.941	1.41	79 (140)	15
Kazakhstan					
Karazhanbas	Jurassic-Cretaceous	0.939	2.10	172 (306)	40
Tataria					
Sugushla	Permian	0.98 – 0.00	3.58–4.79	580 (1032)	100
Shugurovo	Permian		4.4	529 (925)	62
Mordovo-Karmal		0.963 – 0.995	4.7	470 (836)	37
Canada					
Athabasca	Cretaceous	≈1.00	5.5	250 (437) 290 (507)	80–100

"Investigations in this direction have only begun and as yet are of a prospecting nature, but in prospect they may lead to the discovery of new economic types of ores related to natural bitumen and oil.

In connection with what has been discussed, it seems advisable:

1. to do mandatory testing for vanadium, nickel and other metals when proving deposits of bitumen and heavy oils, in particular in the South Tatar-Melekess district of bitumen concentration and asphaltite deposits in the Malaya-Kinel region, the oil fields of Buzsachi Region (Kazakhstan), the bitumen and heavy oil deposits in the Varordey-Adz'va zone and elsewhere;
2. when estimating reserves of bitumen, to make a parallel estimate of the presence of associated metallic components;
3. to reappraise previously proven deposits of heavy sulphurous oil in the Ural-Volga region, Komi A.S.S.R., Nenetskiy National Okrug, Tadzhikstan, on the subject of determining the reserves of metals contained in them (V, Ni, and others)" (Goldberg 1981).

This mandate mentioned by Goldberg 1981 is now very much in place. Engineers and geologists in Komi A.S.S.R. (Yarega), Tataria, Kazakhstan and Baku all indicated work was being done to someday isolate and produce the metal fractions in their oils. The following table indicates the levels of vanadium and nickel found at some of the fields we visited, the values of Athabasca are for comparison.

One of the biggest dissatisfactions with the combustion method was that the heavy metals were lost during the process.

As the research done in this field is relatively new in both the U.S.S.R. and Canada, it would appear that there is ample opportunity for scientists in AOSTRA and the U.S.S.R. to participate in mutual technology development.

INTERESTING THEORETICAL AND EXPERIMENTAL WORKS

The itinerary of our trip was planned by the Soviet hosts who were most interested in showing us practical aspects of heavy oil and bitumen recovery. Therefore, we did not have an opportunity to study cross section of the soviet theoretical and experimental research in porous media. However, there are a few interesting projects which should be mentioned.

Moscow, All Union Oil & Gas Research Institute (VNii)

"Methods of Producing a Porous Medium Model" — Project Leader - Dr Alexander A. Mats.

Realistic models of porous media play an essential role in experimental investigation of displacement processes. Good results in modeling porous media was achieved when soviet researchers applied a well known photomechanical method used in production of electronic chips:

- first, the two-dimensional picture of porous medium is drawn,
- black and white picture of this drawing is made to the appropriate scale,
- specially prepared glass plate is pasted by the photosensitive layer and covered by the negative picture of porous medium,
- after being exposed to the light the photosensitive layer degenerates under transparent areas of negative, thus repeating the picture of porous medium,
- after fixing the remaining part of the photosensitive layer, the plate in submerged into the mixture of aggressive acids and water. Acids corrode the unprotected areas of the glass, thus creating porous channels.

This way any complicated two-dimensional porous medium can be modeled. Work on three-dimensional porous medium is in progress. The authors have published articles and obtained the Author's Certificates on this invention (Mats, 1983).

"Experimental Study of Capillary Displacement" — Project Leader - Dr. Alexander A. Mats.

The object of this study is irreversible oil saturation. A physical model of an idealized two-dimensional porous medium was used to study physical phenomena governing displacement processes (Mats, 1983). The following types of channels and joints were studied:

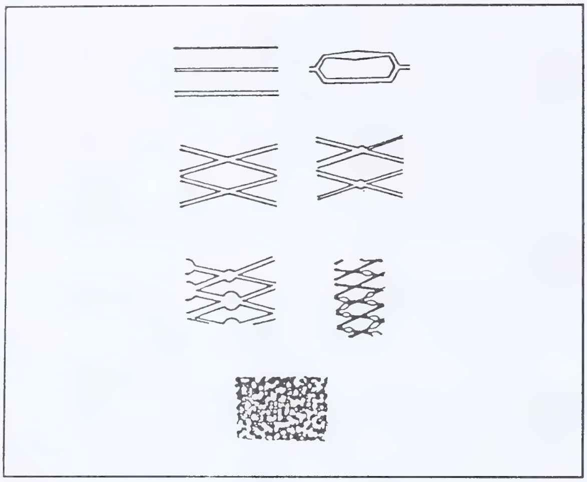


Figure A. Models of capillary channels

Study has shown that trapping of oil occurs in doublets of second type only (Figure B):

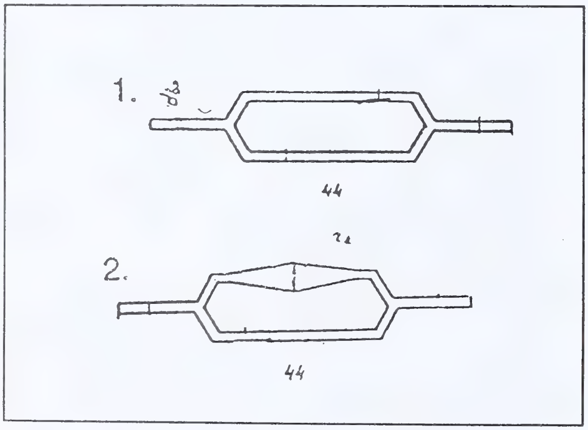


Figure B. Capillary doublets

Different sizes of doublets shoulders were studied and capillary forces were found to be responsible for most of the irreversible oil saturation. For one of the investigated real scale two-dimensional porous media 50% of trapped oil is attributed to balance of capillary forces in doublet, 22% to oil trapped in dead ends and only 28% is not explained by the present theory.

The soviet researchers expressed willingness to cooperate with Canadian scientists on this project as a part of joint venture or otherwise.

"Statistical Hydrodynamics of Porous Media" — Researcher - Mark I. Shvidler

It is a high level mathematical model of flow in nonhomogeneous porous media. Method of averaging is used to describe porous medium as well as fractures of various kinds. This research can be used for interpretation of laboratory experiments.

Moscow, Kiev, Ukhta, Krasnodar

"Cyclic Steam Injection into fractured Porous Media"

The fractured porous medium is presented in the following figure:

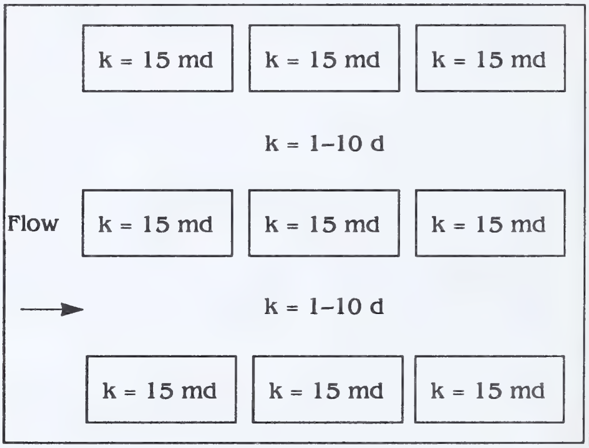


Figure C. Model of fractured media

Zones of lower permeability are called matrices. They do not react on the steam drive, because no significant pressure drop across the matrix can be achieved.

The method of recovering oil from such a porous medium consists of the following steps:

1. the initial steam injection drives oil out of high permeability zones,
2. heating of matrices leads to the thermal expansion of oil which is then flashed out by the steam flow through a zone of high permeability,
3. injection of cold water cools matrices, the oil contracts, and some cold water penetrates the matrices,

4. injection of steam heats the matrices and thermoexpansion of oil permits additional oil to be recovered out of the matrices.

The third and fourth steps are repeated 2-4 times until no more oil appears. This steam-cold water cycling can be regarded as a 'Heat Machine'.

Ukhta

'Deep Drilling Project'

A series of deep drillings are being conducted in different areas of the Soviet Union. The work is in progress and only initial data is available:

- 15 areas are being investigated. Special drilling installations for the standard BU-53/300 derrick (53 meter high) are designed.
- The deepest well has been installed on Kolskii Peninsula, it has reached 12 km so far and is scheduled to go down to 15 km.This well will penetrate all three geological layers.
- Kolskii well has yielded astonishing results:
  1. density of the rock decreases with depth,
  2. traces of water are found up to 12 km deep (the deepest level reached so far),
  3. at the depth of 5 km up to 8% of Helium is found. This discovery can indicate a fusion reaction at the core of the Earth.

We have visited one of the Deep Drilling Sites during our stay in Ukhta. It has reached 5 km so far.

MATHEMATICAL MODELING GROUPS AND COMPUTER SUPPORT

Soviet mathematicians have earned a high reputation for their work concerning application of mathematics to solutions of practical problems. During our trip we met many knowledgeable mathematical modellers working in the field of E.O.R. The theoretical level of their work is very high, but its practical implementation has been limited by inadequate computer support. However, in the last few years much more attention has been paid to the use of computers with many new ones bought from West European suppliers.

Moscow, VNII (Oil and Gas Institute)

Mathematical support is done by a number of laboratories. Dr. Rafail Kats and Dr. Mark Shvidler are the heads of the two laboratories dealing with mathematical and numerical modeling. The computer model is applied to practical calculations of underground flow between coupled wells. There is very little numerical work done in connection with experiments.

Mathematical modeling is presented by various works on fundamental problems of flow in porous media. An example of one of Shvidler's works is described in the previous chapter.

Researchers use different portable computers, but they expect to obtain a larger computer in the near future.

Bugulma, Tatnipineft (Tatarian Oil Institute)

Hydrodynamics Department — 12 people

Head of the Department: Dr. Mugamar M. Musin

The institute offers a number of computer programs for carrying out computations on the estimation of reserves, analysis and oil reservoir engineering.

The specialists of the institute have experience on the development of big heterogeneous computer systems of collection, storage and data processing, geological map plotting and simulation of multihorizon fields.

Description of mathematical model:

- two component: oil and mixture of water and steam,
- number of blocks: up to 2000,
- numerical presentation: final differences, implicit for saturation, explicit for energy,
- language: PL,
- computer: Soviet made ES1030, ES1045 (modified IBM 360-370).

Computer Group — 200 people

Head of the Group: Dr. Rinat M. Yusupov

This group performs various computer workS like the following:

- data processing,
- prediction,
- systems of control,
- evaluation of reserves,
- mathematical modeling.

The institute has its own Soviet made computers (modified IBM 360-370) with the following parameters: 8 Mb operation memory, 16 Mb virtual memory, 1.5 million operation per second.

The group uses card feeder and 8 on-line terminals with one terminal per four operators per day. Cost of one terminal is 5000 rubles.

Kiev, Ukrgiproniineft (Ukrainian Oil Institute)

Mathematical Modeling Group

Head of the Group: Dr. Yurii S. Abramov

Until 1975 only analytical methods were used.

In 1975 the Institute bought their first microcomputers and the group started to program oil displacement model.

Up to 1983 they worked with finite differences scheme and from 1983 finite elements took over. Today the two-dimensional three-component model is expanded to include gas.

Baku, Academy of Science of Azerbaijan SSR

Department of Non-Linear Mechanics of Oil and Gas

Associate Research Officer: Dr. Vadim Azizov

Major projects:

- control of production well,
- well coupling,
- heavy oil,
- gaslift.

Computers: Amstrat - 640 kb, Winchester - 30 Mb.

LIST OF CONTACTED SPECIALISTS

1. MOSCOW

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Zotov, Alexander N. – Head of Foreign Relations Department

Mats, Alexander A. – Dr., Head of Laboratory
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Shvidler, Mark I. – Dr., Head of the Laboratory
Kerimov, Ekram M., – Dr., Senior Scientific Associate
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Nikitin, B. – Deputy Minister, contacted on pipelines problem

2. UKHTA

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Belevich, Alexander S. – Chief Mechanic

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Ruzin, Leonid A. – Head of Laboratory in Thermorecovery, Chief Technologist on Development of Usa Method

3. OKHA, YUZHNOSAHALINSK (SAKHALIN ISLAND)

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4. BUGULMA (TATARIA)

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APPENDIX 1

Ukhta - Yarega

1. Talks with Dr. Tabakov.
2. Diagram and figures about Yarega, (translated from MNTK documents).
3. Comparison between AOSTRA UTF Facility and Yarega Underground mines.
4. Brochure – "Methods of Thermal-Mine Oil Fields Development" by MNTK.
5. Paper – "Recovery of Hydrocarbons from Oil Sands and Oil Shales by Mining".
6. Paper – "Practical Aspect of Recovering Heavy Crude, Bitumen and Oil Shale".

MEETINGS WITH DR. V.P. TABAKOV

In Moscow at MNTK headquarters, I had the pleasure of meeting Dr. V.P. Tabakov to discuss thermal methods, and in particular, the shaft method of oil production. Dr. Tabakov is one of the most prominent scientists in the U.S.S.R., concerning the shaft method. He has worked on these projects since the 1950's and published a variety of papers and books on the methods. Listed in point form are the selected notes from our discussions:

General

- There is a large gap between scientific and theoretical work and plot and commercial implementation. This happened in the 1960's and 1970's because of the massive amounts of cheap oil available. Money and equipment was not allocated for pilot projects to test the theoretical concepts developed. They are now trying to catch up with the WEst, however, they are badly lacking in good equipment.
- Up to now, the U.S.S.R. has produced from clean homogeneous deposits. To keep up with declining production they have to develop and deal with heterogeneous deposits. They have a strong mandate in this field.
- The U.S.S.R. have drilled horizontal holes up to 680 meters (1984). They ceased at this point because they felt it was the maximum distance they needed to go. Their horizontal drilling technology was first developed in the 1960's.

Yarega

- The deposit is 130–200 meters deep, consisting of a hard quartz sandstone. Of significance is the fracturing within the deposits. It consists of large scale fracturing with each block 20–30 meters across, and displacements of blocks up to 5 meters. Within each block there is small scale fracturing resulting in blocks of 0.5–1.5 meters across. This fracturing has both positive and negative effects on the oil production.
- The deposits contain shale lenses 10–15 meters in length and 2–4 meters thick. The deposits lie on a water saturated compressed shaled which is non-penetrable.

History

1936 – Primary recovery by surface wells (discovery).
– Flow was poor, recovery 1.8% O.O.I.P.

1938 – First shaft was completed.

1939 – First oil was produced by the underground shaft method (UKHTA method).
– A refinery was built, in fact during World War II, UKHTA was the only oil supply for Leningrad.

1939 – 1953 Oil produced by the UKHTA method. Wells were drilled from tunnels 20 meters above the producing zone.
– Each unit worked 2 years.
– There were very high initial pressures and a gas cap. Original production was high, up to 40 tonnes day, however, after two months the pressure dropped off and production became negligible.
– Air was then pumped into the wells from a 1" tube inserted into the wellbore and oil was blown up the outside of the tube to the well head (called Air-lift method).
– All hotels were open, i.e. no casing.
– They developed in the thickest part of the reserve with the highest oil saturation.

1955 – 1974 Inclined (Slope) Unit Method or the Slant Well System was implemented
– A 15° slope shaft was built into the producing formation and the end of which was a slope production unit or production gallery.
– The production galleries were built 5 meters from the bottom of the payzone, just above the water contact. The production units were hexagonal in shape.
– Up to 300 wells form horizontal to 12° deviation were drilled into the formation and production occurred by gravity.
– Waterflood injection was tried, however, it was not successful due to the fact the water escaped through the fractures within the payzone.
– The last gravitation slope was shut down in 1974.

- Recovery was 3–6% O.O.I.P. (closer to 3%).

1968 – In the late 60's production had dropped to such a low level that they considered shutting down the project. Scientists suggested using steam to stimulate oil flow. The production people did not want to try new methods but were finally forced to, as a last resort. The major gas pipeline near the field made construction of steam plants quite practical.

- Several systems have been tried since 1968. They include a system which combined the vertical holes of the old UKHTA system and the slope well production units. The vertical wells were used to inject steam and horizontal wells from the slope units were used to produce.
- The second system is the Panel System where all wells injector and producer are drilled within the pay zone at various angles and spacings.
- Today 90% of the production of Yarega is by the panel system. Daily production 1400 tonnes/day.
- The advantages of this method were no heat loss to unproductive strata, well drainage is more even and daily oil production rates are more constant.

Production Data

- Production wells are 300 meters long, with casing of the first 20 meters.
- Production Gallery is 60 meters in circumference with a diameter of 20 meters. Height is 2.8–3.0 meters.
- Steam to oil ratio averages 2.7 tonnes steam/1 tonne oil
- Production for 1988: 503 thousand tonnes.
- Production projections 1991:

Shaft	Production tonnes/year
1	350
2	150
3	250
2B	305
	1.05 m tonnes/year

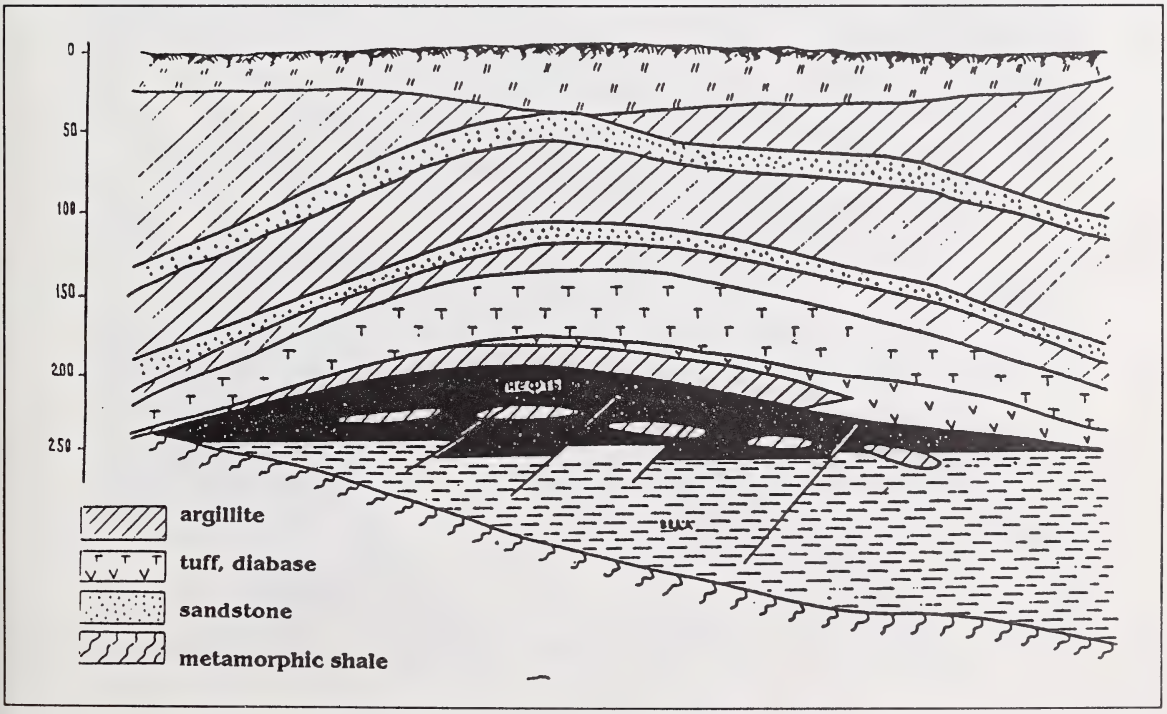
- Shaft 2B is under construction and when completed will be a complete self contained unit. Plans are for it to open in 1990.
- The ultimate plan is for 6 mines to produce 1.66 million tonnes/year.
- Final recovery is projected at 45–50% of O.O.I.P.

Miscellaneous Data

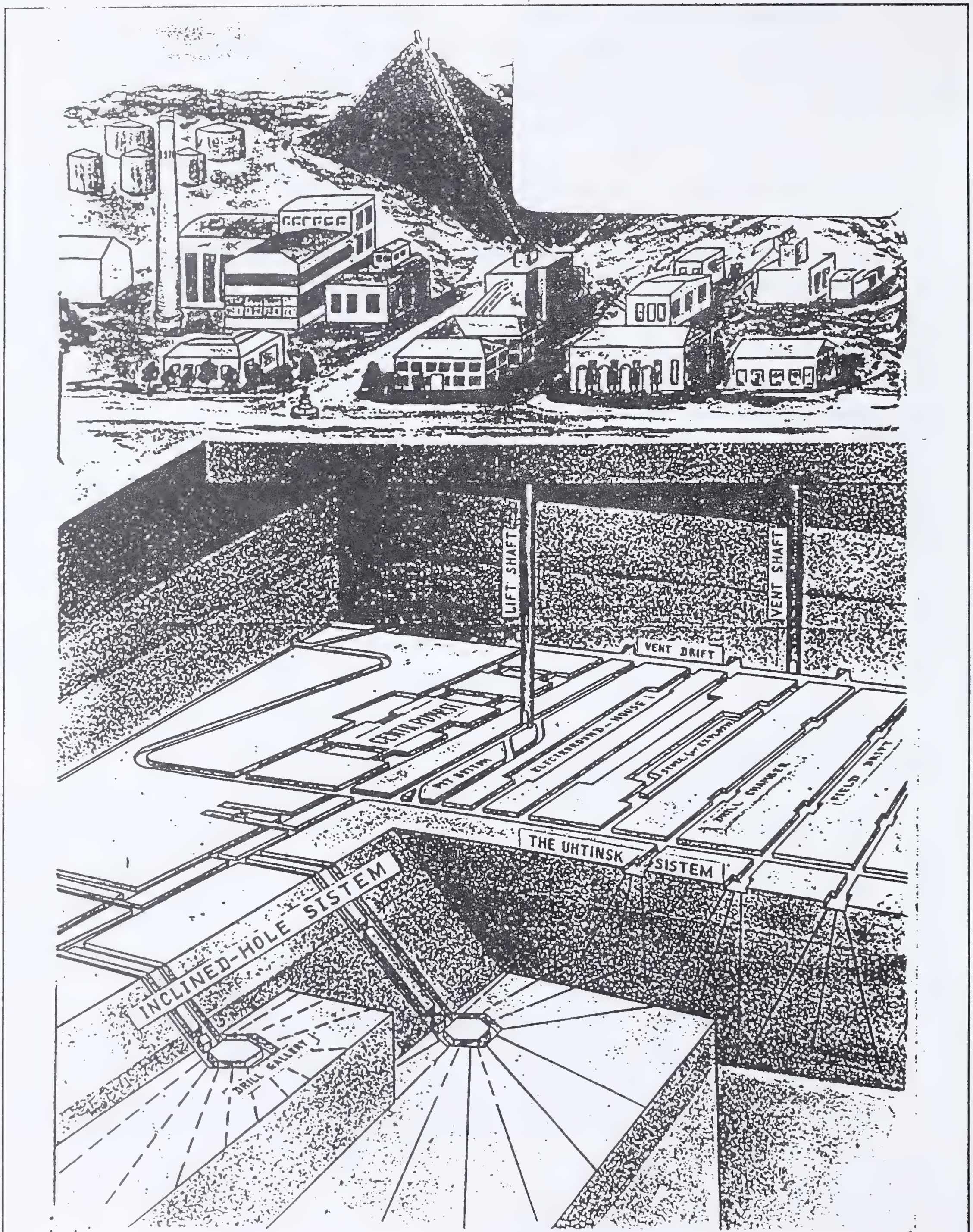
- Underground drill
  - Bit diameter 96 mm
  - Drill pipe length: 2 m.
- Average temperature
  - 26°C in the shaft, the producing gallery average 34–36°C. When temperatures reach 40° in the production gallery operations are stopped.
- Shafts are built by conventional methods, i.e., explosives and waste removal by miners from Dombass and Kybass coal pits.
- Drilling costs
  - 1d ruble per meter without casing
  - Surface horizontal drilling costs are 90 rubles per meter
- Projected reserves for each panel is 320 thousand tonnes. They calculate it will take 8.5 years to reach 45% oil recovery for each panel area.
- Future plans call for shafts from 500 to 1000 meters deep. They believe this method can be used to develop heavy oil deposits under permafrost and also from manmade islands in shallow seas.
- Shaft method is one half of the cost of using surface steam injection methods. Their major capital cost is the shaft, however, they calculate an average steam oil ratio of 2.6 tonnes steam per 1 tonne of oil for the shaft method, compared to a ratio of 6.5 tonnes steam/1 tonne oil for surface methods.
- Of late they inject hot water to keep the reservoir temperature up and also viscosity agents (?) to close fractures with the high pressure steam.

Prospectives of Shaft Development (Tabakov)

- These parameters have been developed to apply to heavy oil and natural bitumen deposits (viscosity of >50 cp) for development criteria:
  - Reserves per shaft not more than 5 million tonnes
  - Depth up to 800 meters
  - Reservoir thickness >5 meters
  - Carbonate or sandstone
  - Must be consolidated competent rock
  - Porosity >18%
  - Permeability >100 md
  - Viscosity >80 mPa/cm³
  - Density >880 kg/m³
  - Oil saturation >6% wgt
>50% volume
  - Gas saturation ≤10 m³/tonne of oil
- Using these parameters for development, the Soviets have increased their recoverable reserves by over 5 billion tonnes.
- Initial data required for preliminary design of a project included (quotes from presentation):
  - Area, depth, length, width, pay thickness, gross thickness, net thickness;
  - Geometry of the oil zone, water zone;
  - Porosity, permeability, permeability distribution, oil saturation, water saturation, gas saturation;
  - Reservoir temperature, reservoir pressure, oil in place, initial gas in place, gas saturation pressure, gas content (solution gas at reservoir temperature, oil density and viscosity);
  - Thermal rock conductivity, reservoir rock density;
  - Specific thermal capacity of the reservoir rock.
- They then develop a project by elements. Determine optimum unit size and production profile. Unfortunately their production profiles are usually not met due to equipment and breakdown problems.

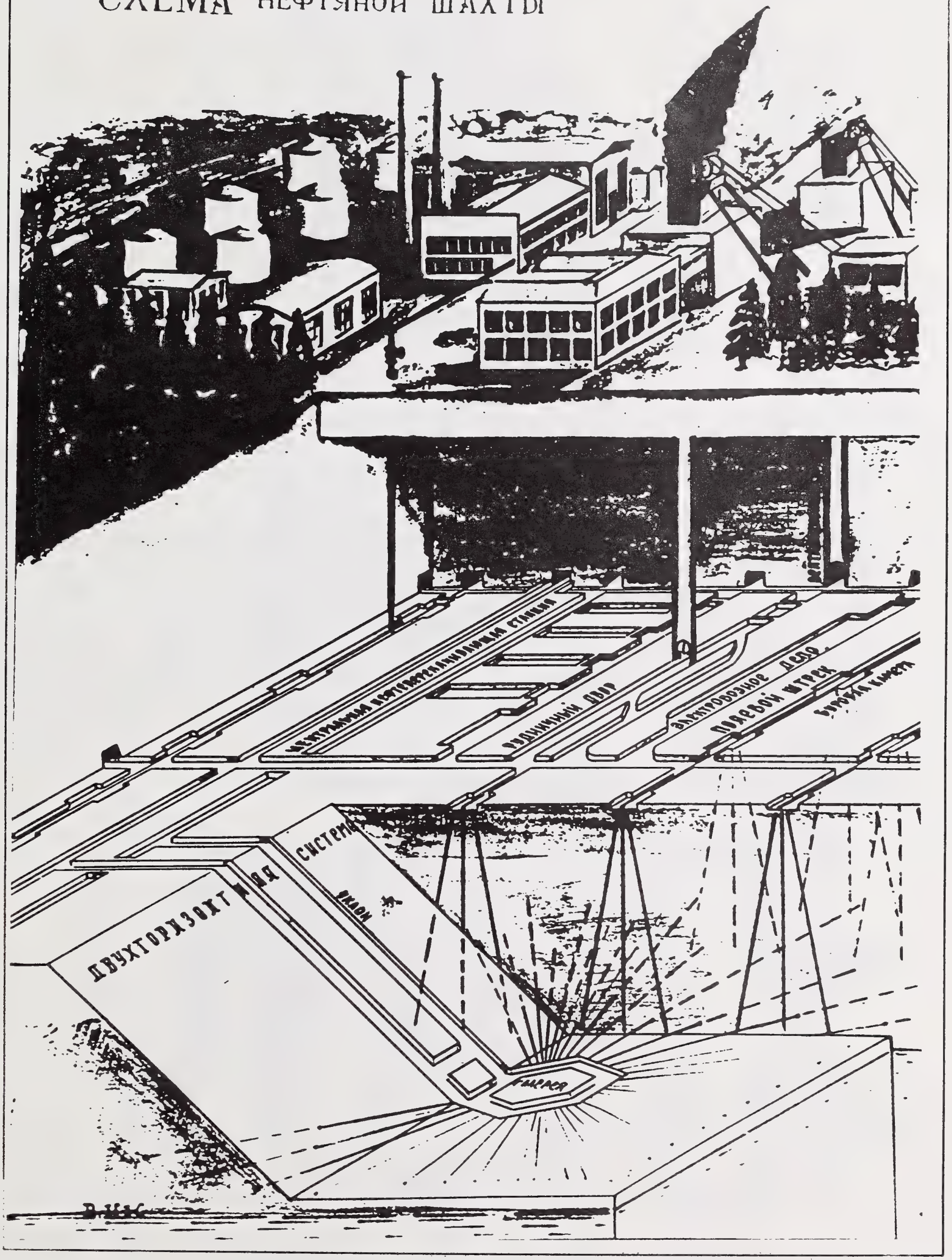


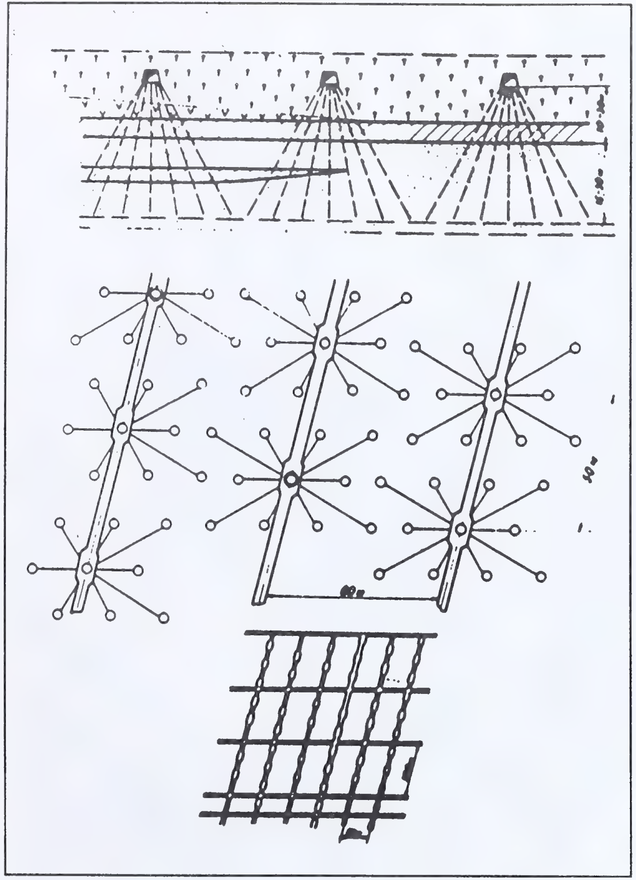
Yarega Deposit



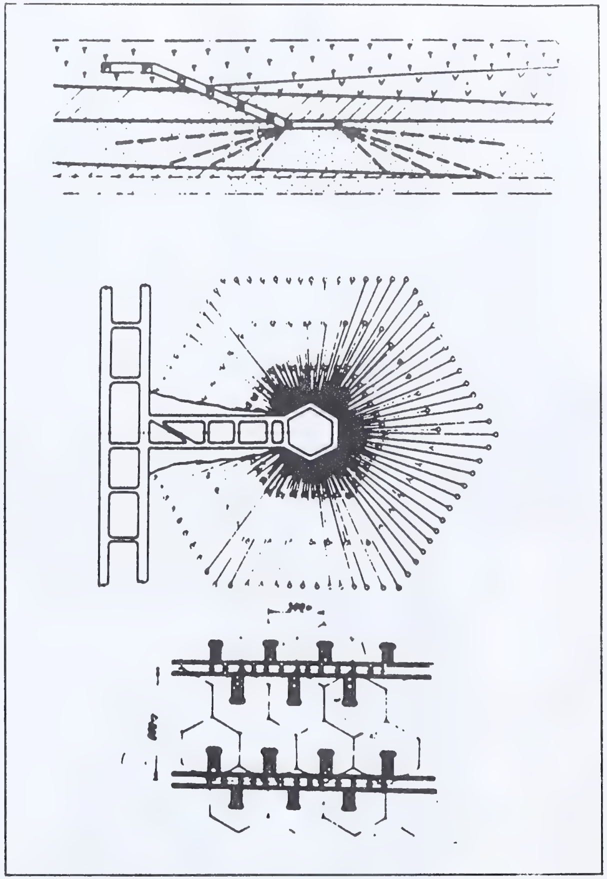
Scheme of the Jarega oil-producing mine

СХЕМА НЕФТЯНОЙ ШАХТЫ

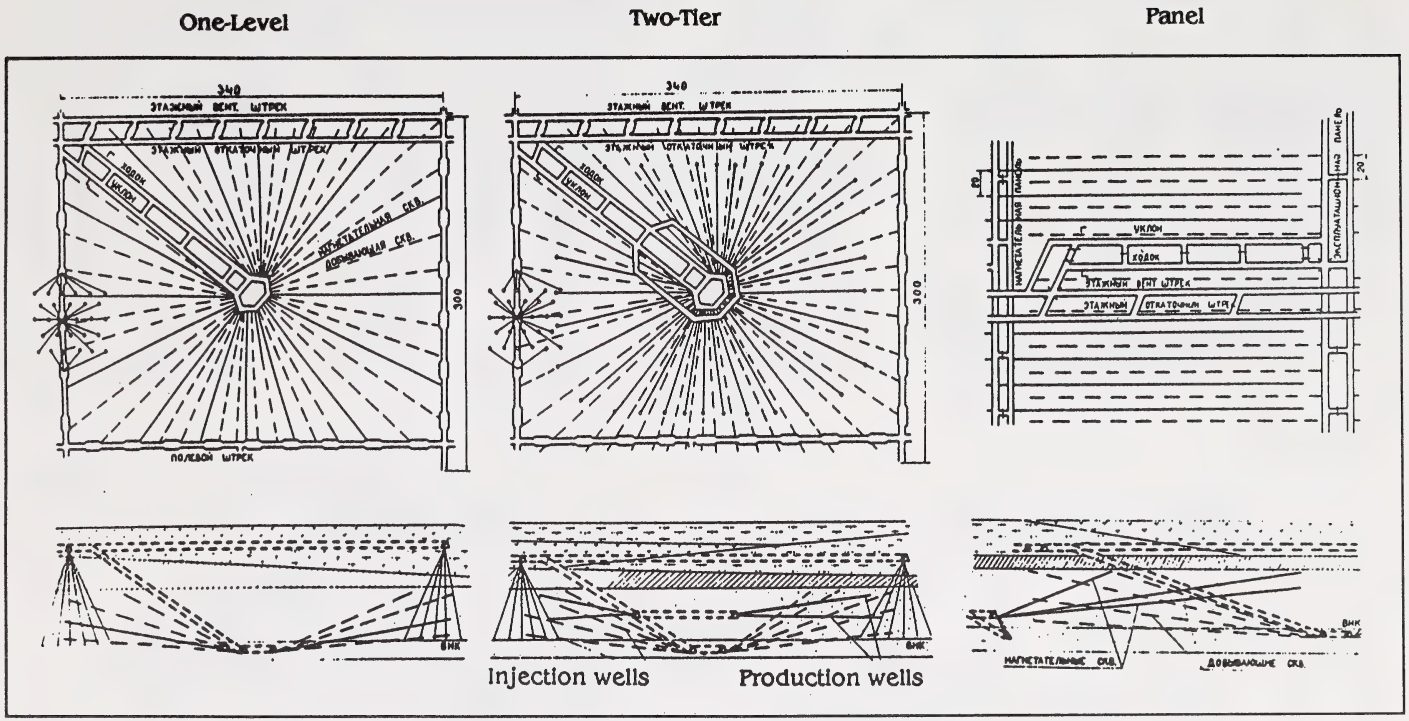




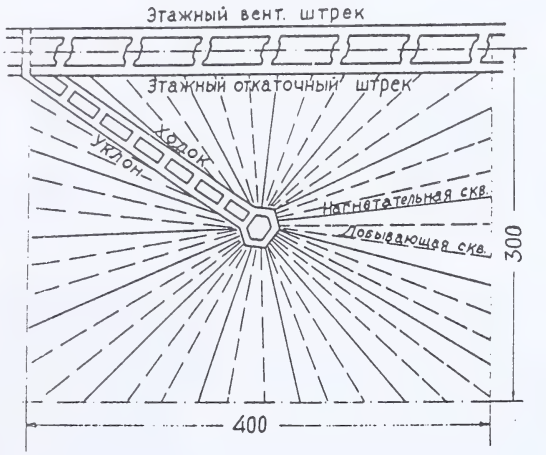
Ukhta Method

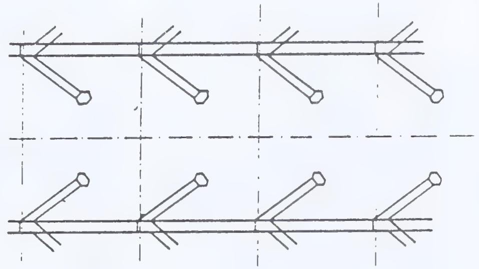


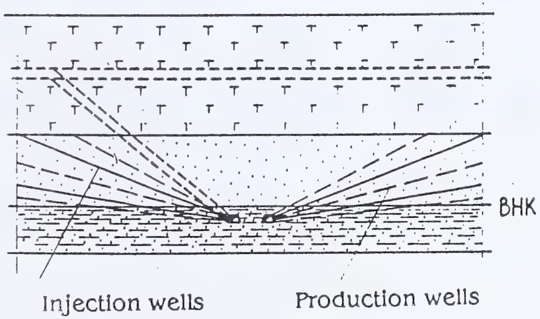
Slope-Well Method



Method of Development

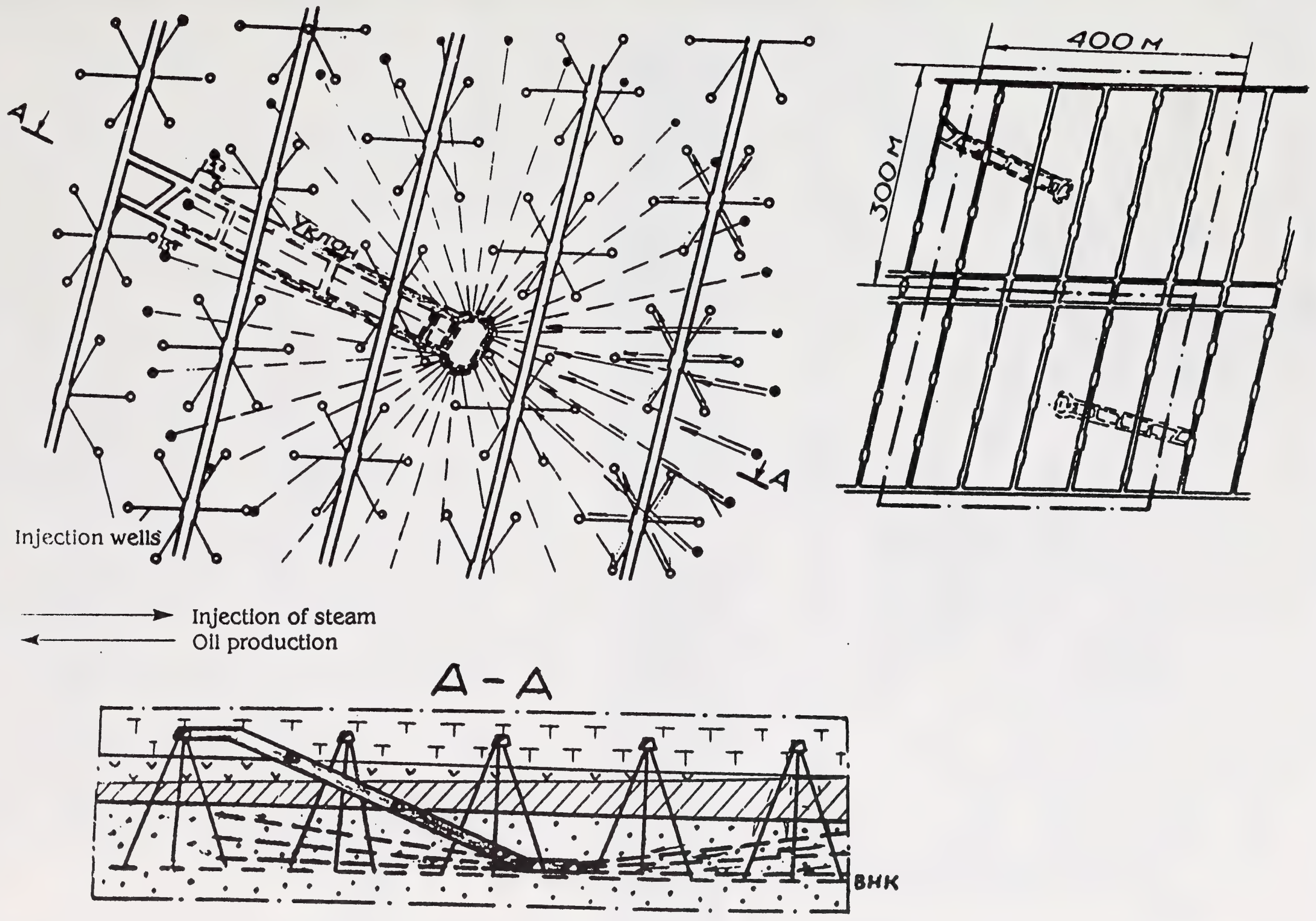




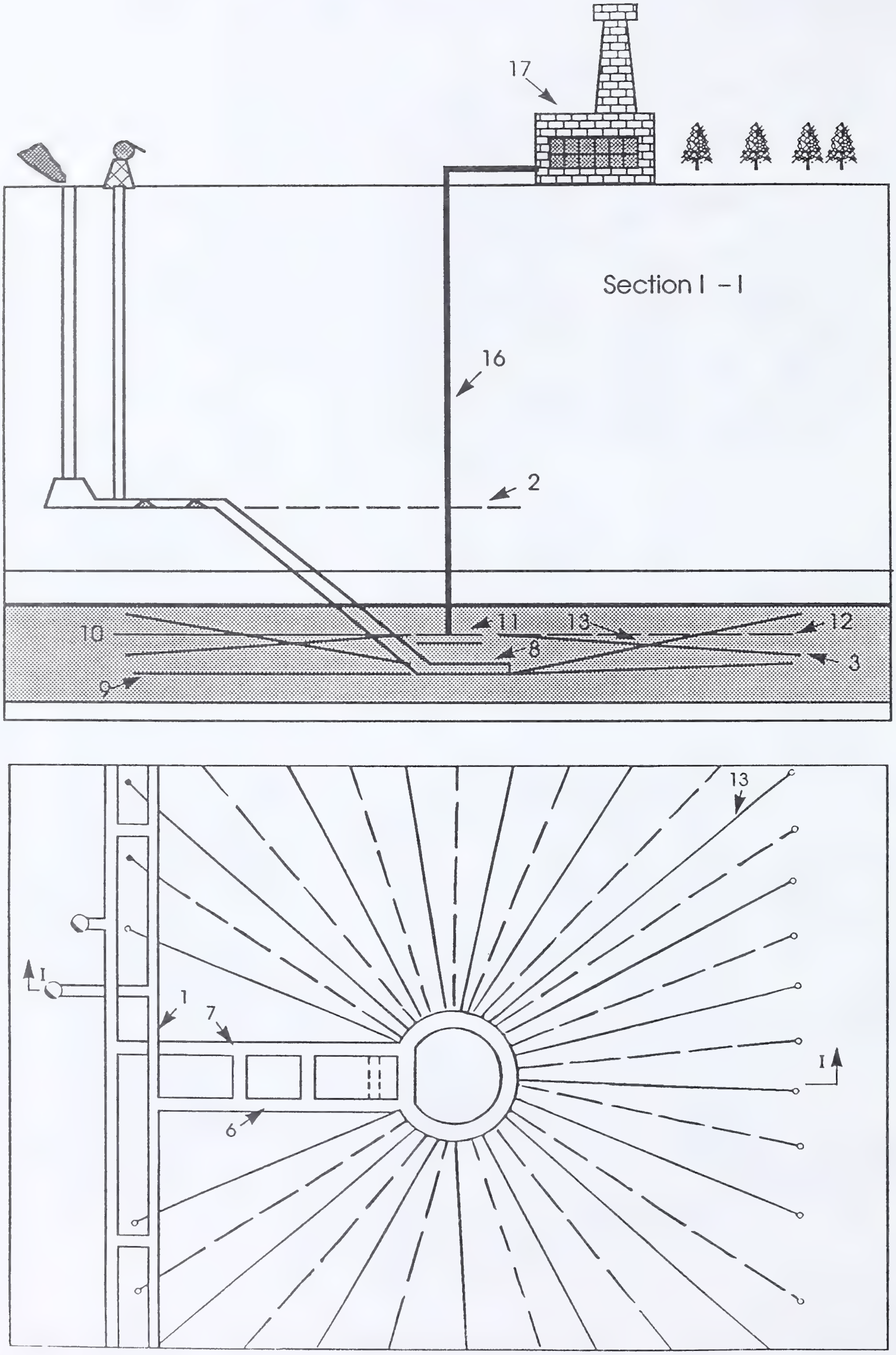


Characteristics	Unit	Per unit	Per 1 ha
Length of tunnels	m	1040	87.7
including: floor	m	400	34.4
slope	m	370	30.8
pay zone	m	100	8.4
connectors	m	140	11.6
others	m	30	2.5
Length of wells			
from tunnel	km	35	2.9
from surface	m	180	15.0
Steam pipeline D = 100 mm	m	100	8.4

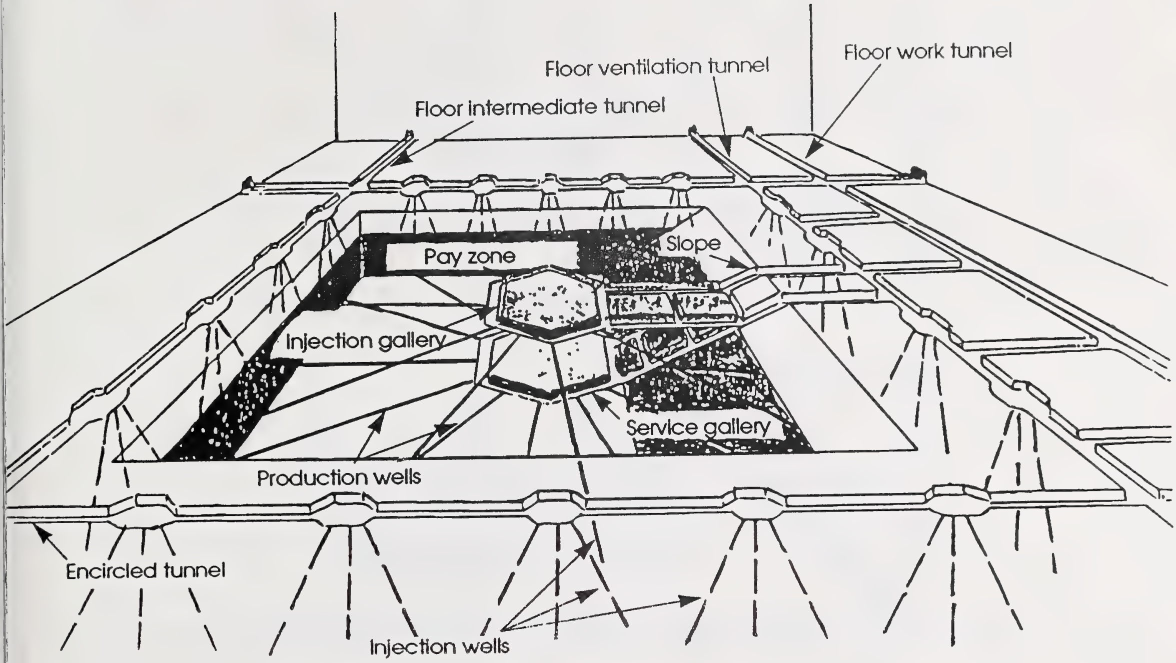
One Level Method
Area of slope unit is 12 ha



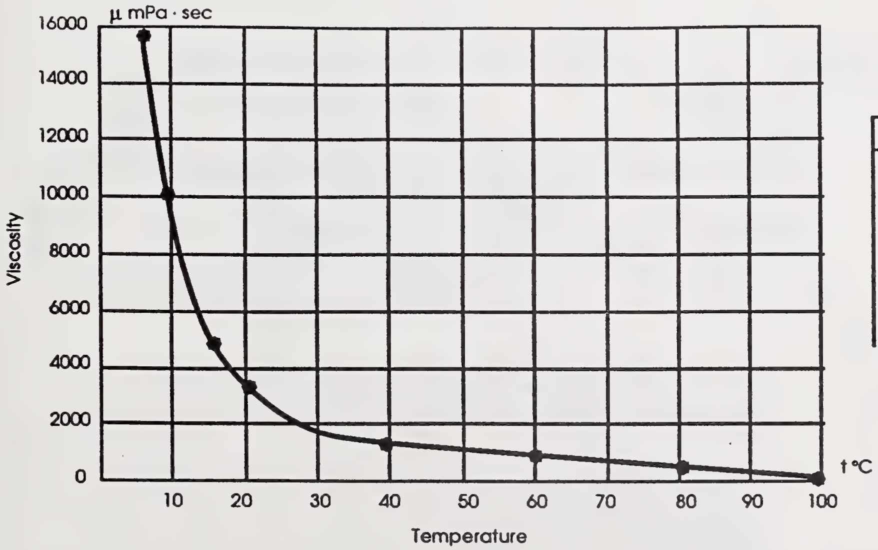
Two-tier method with thermal E.O.R. (Yarega deposit)



Two-tier system

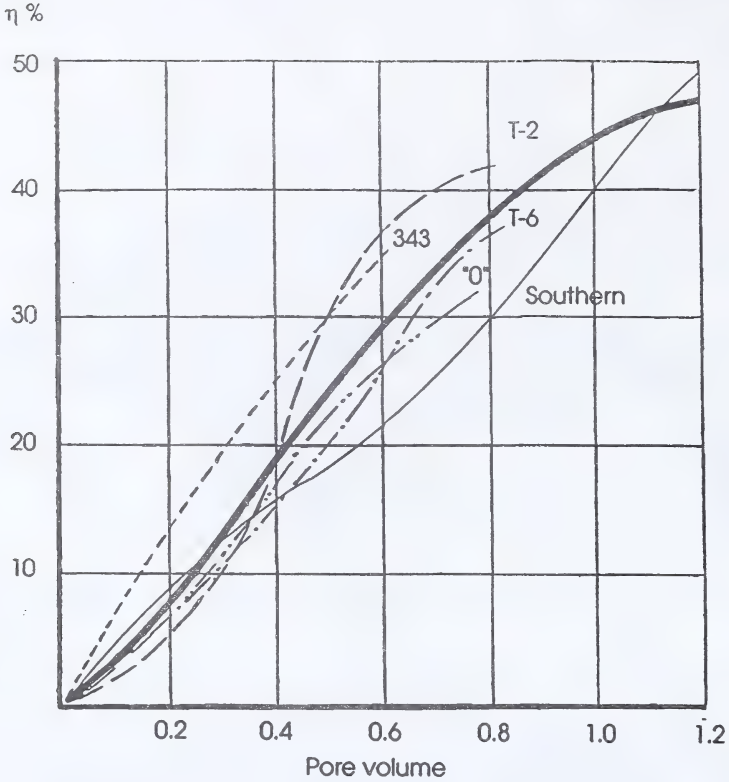


Two-tier system with encircled production zone

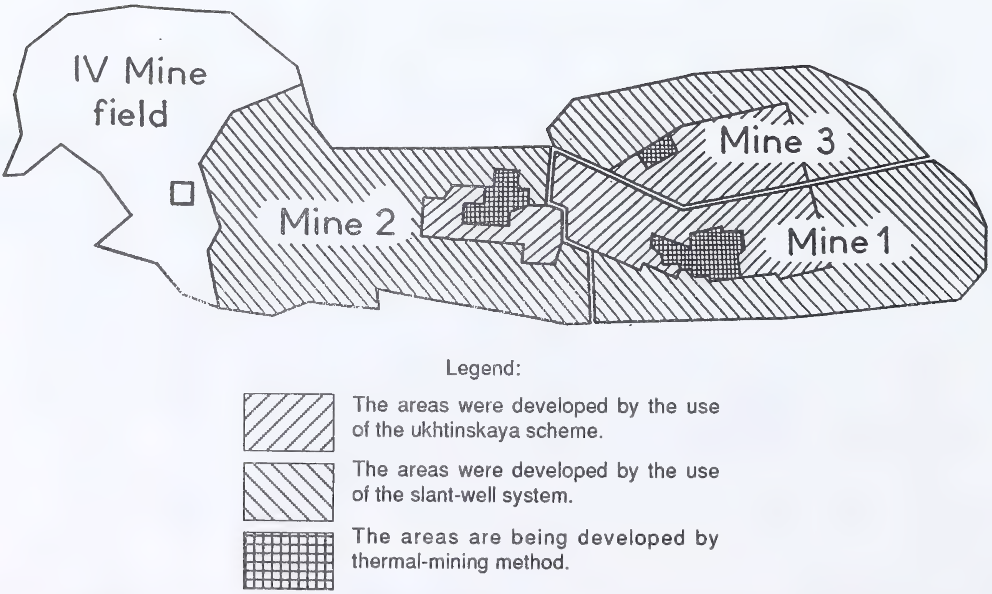


t °C	μ mPa · sec
5	16080
10	10060
20	3420
40	633
60	182
80	72
100	29.5

Viscosity of Yarega oil



Oil production versus injected steam production zone



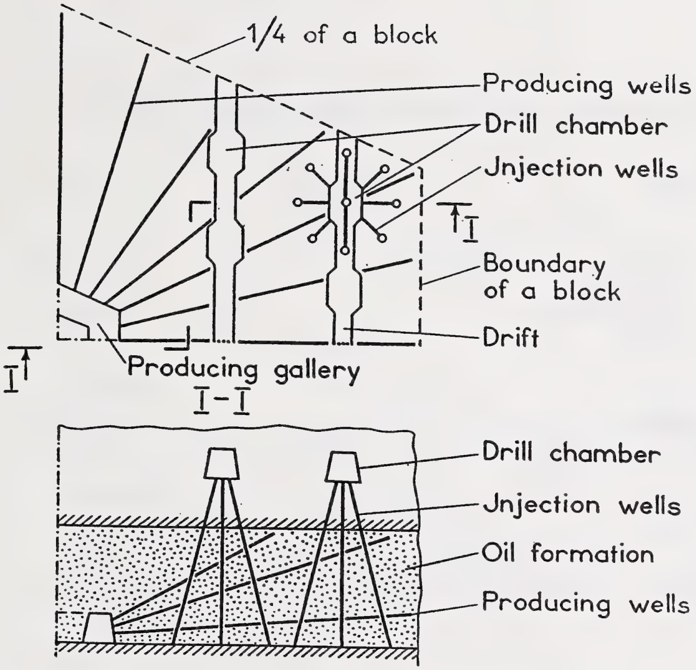
Legend:

▨ The areas were developed by the use of the ukhtinskaya scheme.

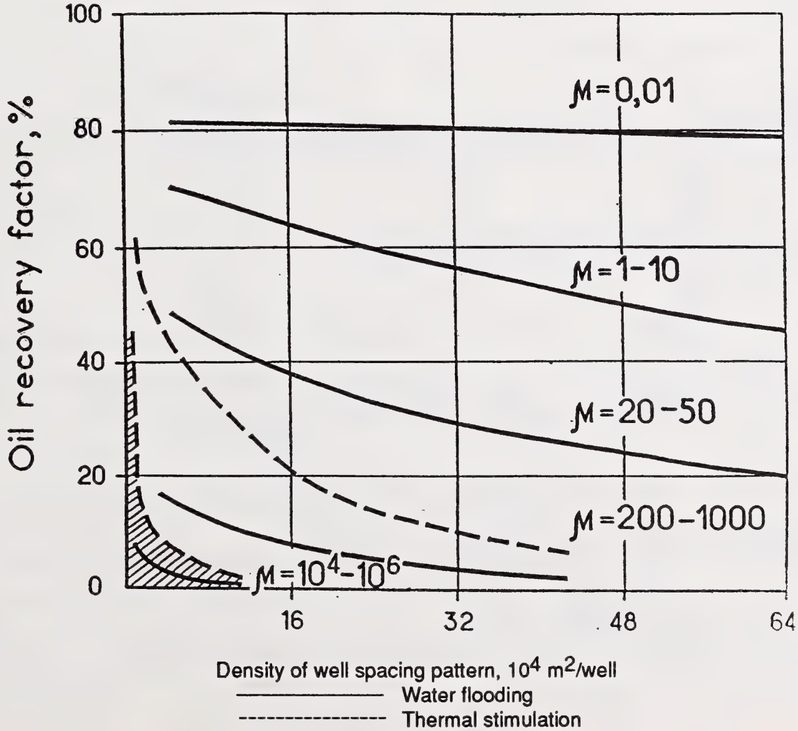
▧ The areas were developed by the use of the slant-well system.

▦ The areas are being developed by thermal-mining method.

Yarega oilfield. Zones of application of various systems of mining development



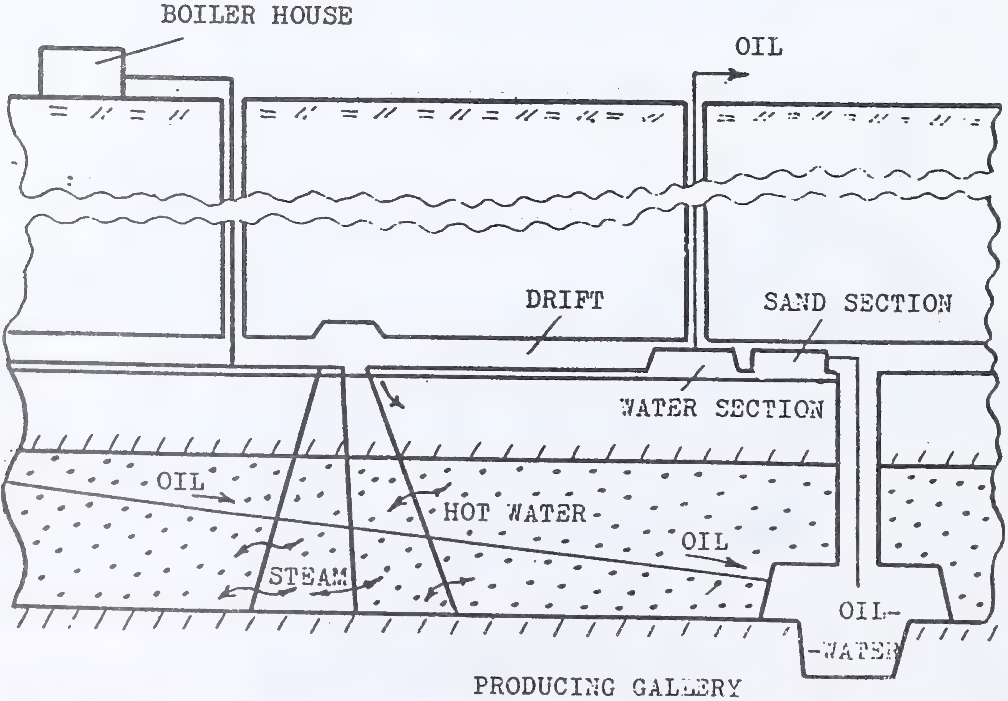
Yarega oilfield. Two-horizontal system of thermal-mining development



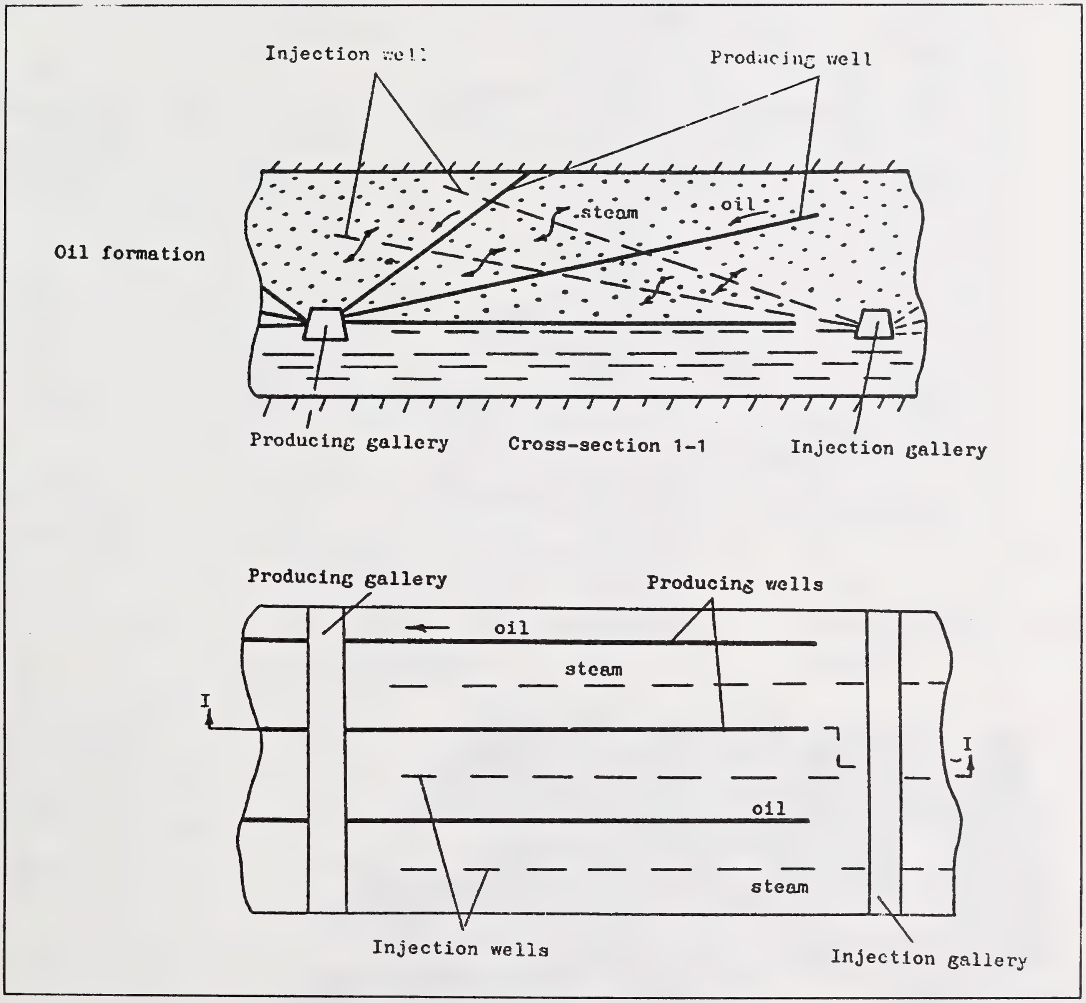
Oil recovery factor versus density of well spacing pattern and method of stimulation

Critical factors for application of the shaft-well technique of oil production

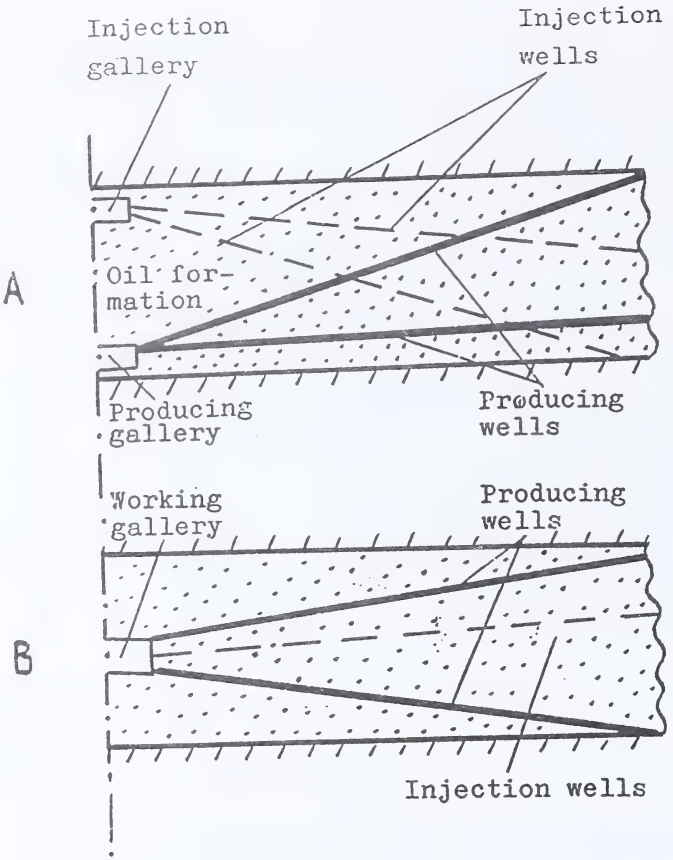
Parameters	Dimensions	Value
Depth of occurrence	m	up to 800
Reservoir thickness	m	over 10
Rock strength	kg/cm^2	over 100
Gas saturation	cu.m/t	less than 10
Temperature	°C	less than 26 ... 60
Oil and bitumen content:		
– mass	%	over 6
– volumetric	%	over 50



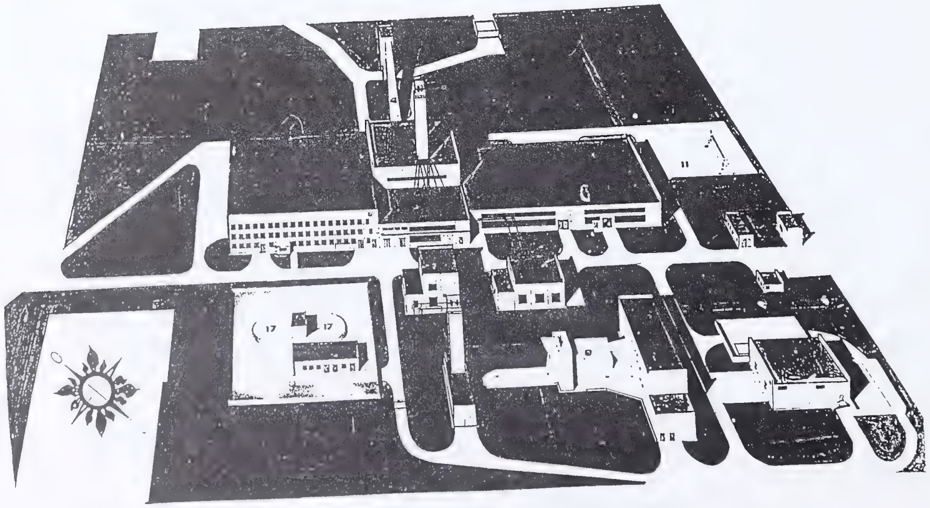
Scheme of thermal-mining development of heavy-oil and natural bitumen deposits



Yarega oil field. Scheme of panel system of thermal mining development



Yarega oil field. Schemes of two-stage (A) and one-horizontal (B) thermal-mining development



1. Facility building
2. Head frame
3. Auxiliary shops
4. Disposal tunnel
5. Rock transport station
6. Ventilation building
7. Cage building
8. Ventilation unit
9. Ventilation channels
10. Transformers
11. Warehouse
12. Disposal place
13. Sewerage
14. Boilers
15. Fire pumps
16. Control chamber
17. Reservoirs
18. Training site
19. Shipment unit

Oil shaft no. 2, "Yareganeft"

Yarega Underground Thermal Mines

LOCATION: 35 km SE, UKHTA
Komi, A.S.S.R.
U.S.S.R.

OWNER: Komineft

PROCESS:

Shaft and tunnel access to horizontal well drilling

Current Process

Panel System – 2 well horizontal system (C).

Drillhole Length – up to 300 m

START UP:

- 1933–1939 • Primary production
- 1939–1955 • UKHTA method
- 1955–1973 • Slope shaft methods
- 1968–Present • Slope shaft method with thermal stimulation

RESERVOIR:

Geological horizon – Middle Devonian
Depth to top of formation– 180–200 m
Reservoir area – 12km x 3km, 36 km²
Reservoir thickness – 17m–26m
Lithology – Quartz sandstone
Reservoir temperature – 6–8°C
Reservoir pressure – 14–15 Atm
Average permeability – 3 d
Average porosity – 26%
Average water saturation – 13%
Average oil saturation – 87% pore vol.
Oil viscosity at reservoir temp. – 15,000–20,000 cp
Oil gravity at reservoir temp. – 933–966 kg/m³
Production – 503 k tonnes/yr 1988 (3 mines)

MINE STATS:

Number of shafts – 3
Total area mined to date – 1000 ha
Total tunnels developed – 600 km
Shaft diameter – 6 1/2 m
Shaft depths – 180–200 m
Slope grades – 15°

PRODUCTION UNIT: (B)

Circumference – 60 meters
Radius – 10 meters
Diameter – 20 meters

TUNNELS:

Height – 2.8–3 meters
Width – 3.5 meters
Area – 10 m²

DRILL:

Bit diameter – 96 mm
Drill stem – 2 m
Drill rotation – 360°
Production – 100m/8 hr shift
Type – Hydraulic

GAS: < 2% methane

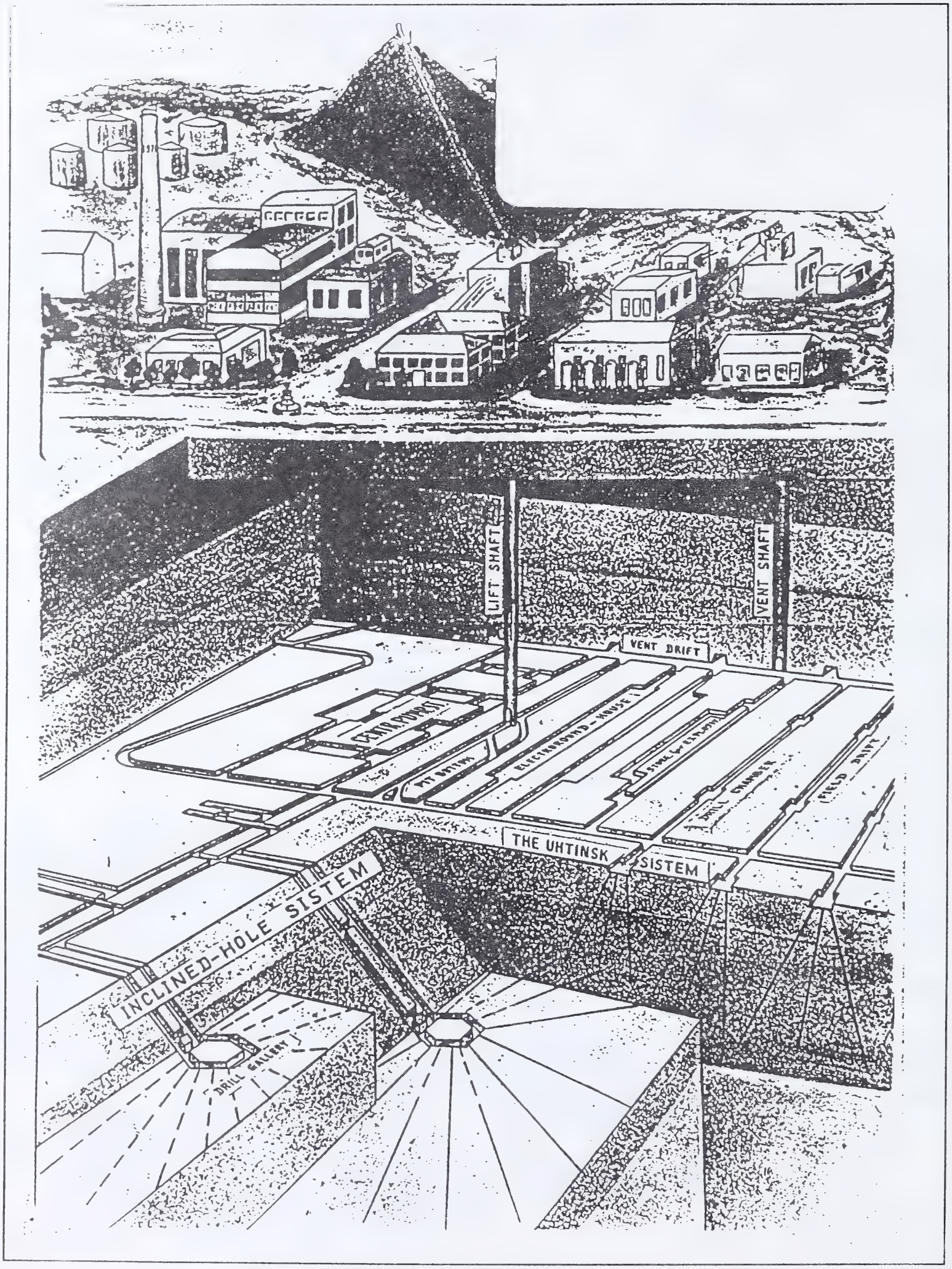
STEAM GENERATORS: (Shaft #1)

3 Units, U.P.G. 9/120
9 tonnes/hr @ 120 atm.
Fuel - natural gas

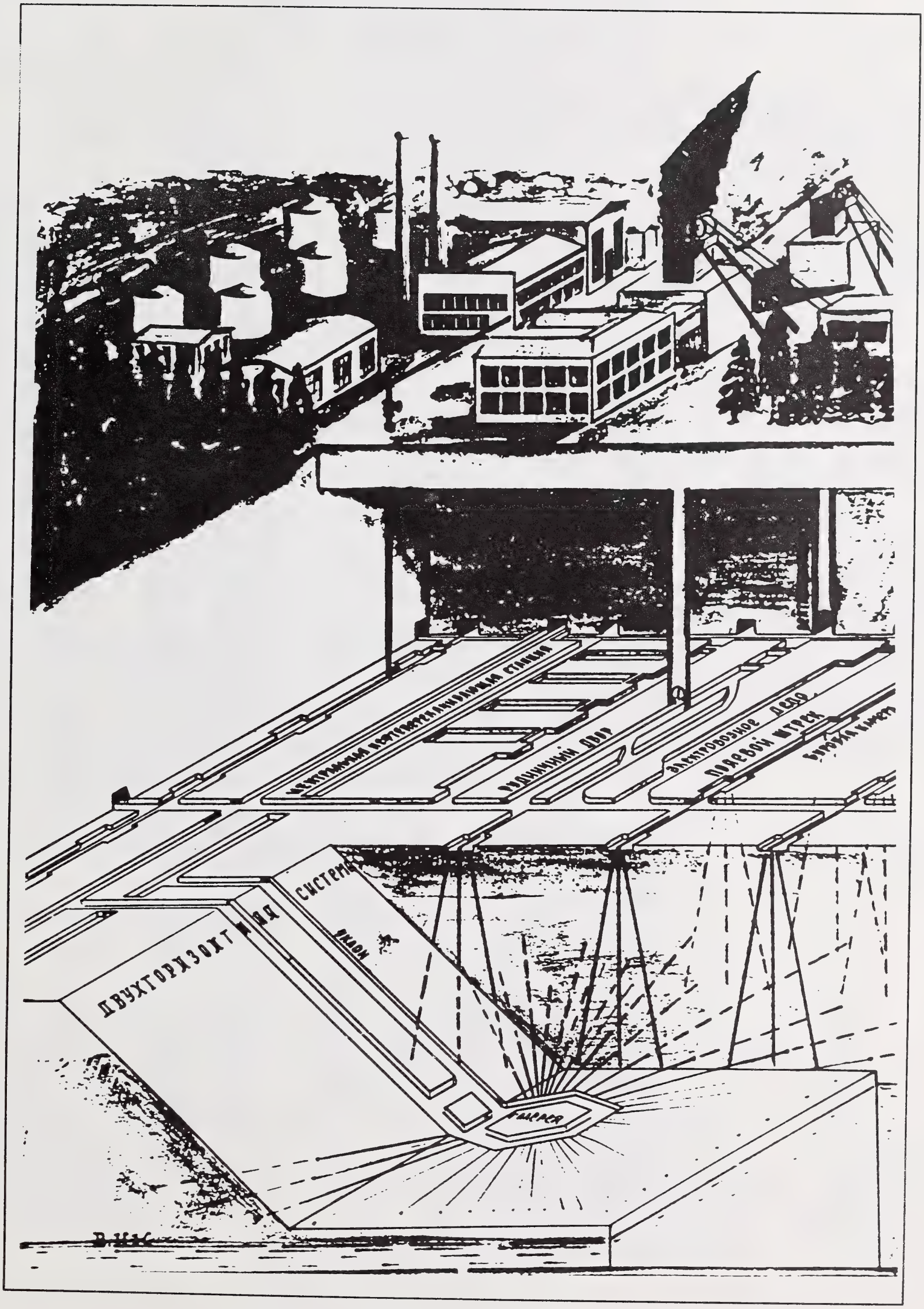
STEAM-OIL RATIO: Avg 2.7/1

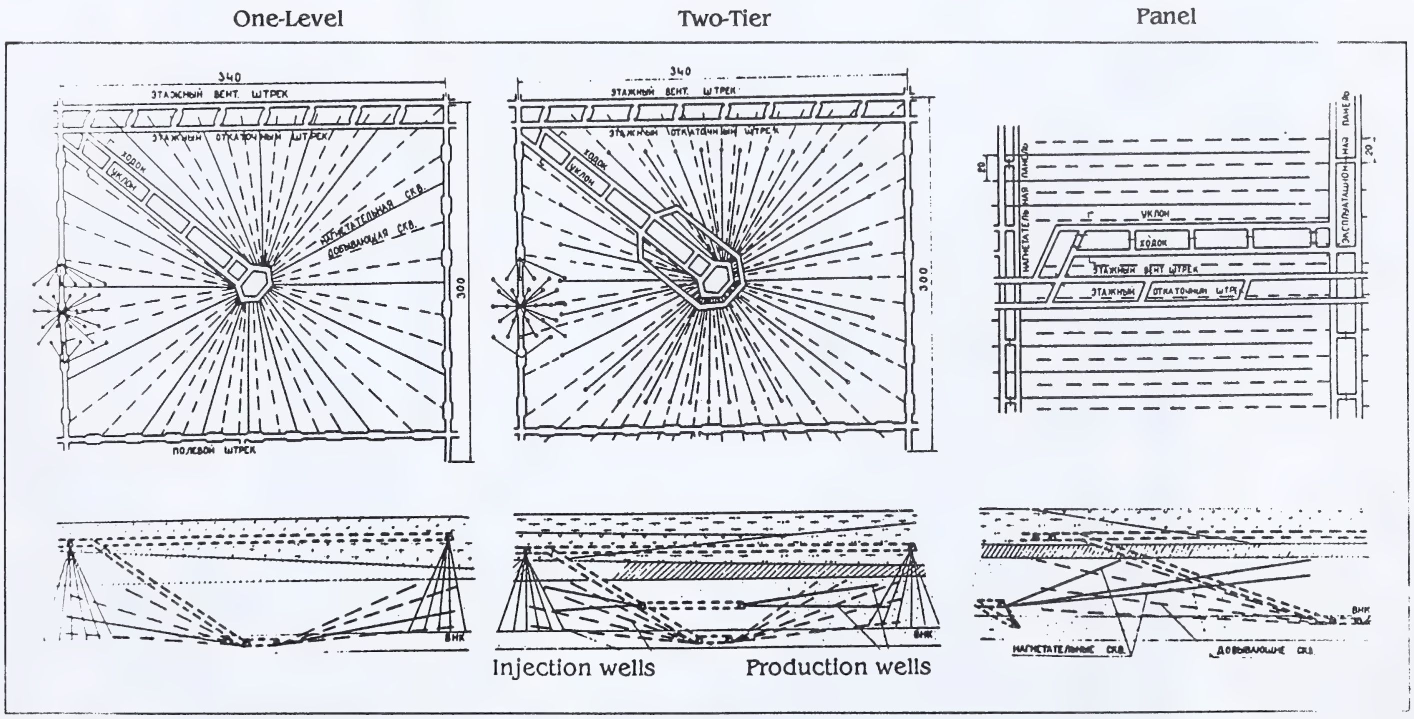
MISCELLANEOUS:

Distance to refinery – 100 km by rail
Temperature – Tunnels – 26°C
Production units – 34–36° C
New mine to open in 1991
Proposed total prod. 1991 – 1.06 m tonnes/yr



Scheme of the Jarega oil-producing mine


ЦЕНТРАЛЬНАЯ [illegible] СТАНЦИЯ
РУДНИЧНЫЙ ДВОР
ЭЛЕКТРОВОЗНОЕ ДЕПО
ПОЛЕВОЙ ШТРЕК
ВЗРЫВНАЯ КАМЕ
ДВУХГОРИЗОНТНАЯ СИСТЕМА
УКЛОН
ГАЛЕРЕЯ



Method of Development

AOSTRA Underground Test Facility

LOCATION: LSD 2, 3, 14 & 15
Section: 7, 18
Township: 93
Range: 12 W4M

PARTNERS:

Access Stage – 100% AOSTRA

- Phase A Process Tests
  - AOSTRA
  - Amoco Canada Petroleum Company Ltd.
  - Canadian Centre for Mineral & Energy Technology
  - Chevron Canada Resources Ltd.
  - Mobil Oil Canada
  - Petro-Canada Inc.
  - Shell Canada Ltd.
  - Texaco Canada Resources Ltd.
- HASDrive Process
  - AOSTRA
  - Chevron Canada Resources Ltd.

PROCESS:

Shaft & Tunnel Access to Horizontal Well Drilling

Horizontal Well Process:

(i) Steam-Assisted Gravity Drainage (SAGD)
(ii) Heated Annulus Steam Drive (HASDrive)

COST: $56,000,000 mine/wells/facilities/roads

START-UP:

Mine Access: September 1986
Phase A Processes: November 1987

TERMINATION: Phase A estimated 1990

DESCRIPTION: Phase A: 1.0 ha
HASDrive: 0.3 ha

WELL PATTERN:

Phase A:	3 pairs of horizontal wells; 160 m length; end 60 m completed 26 m between wellpairs
HASDrive:	160 m horizontal heating well; vertical injector at far end; horizontal producer 60 m back on heating well

OBSERVATION WELLS:

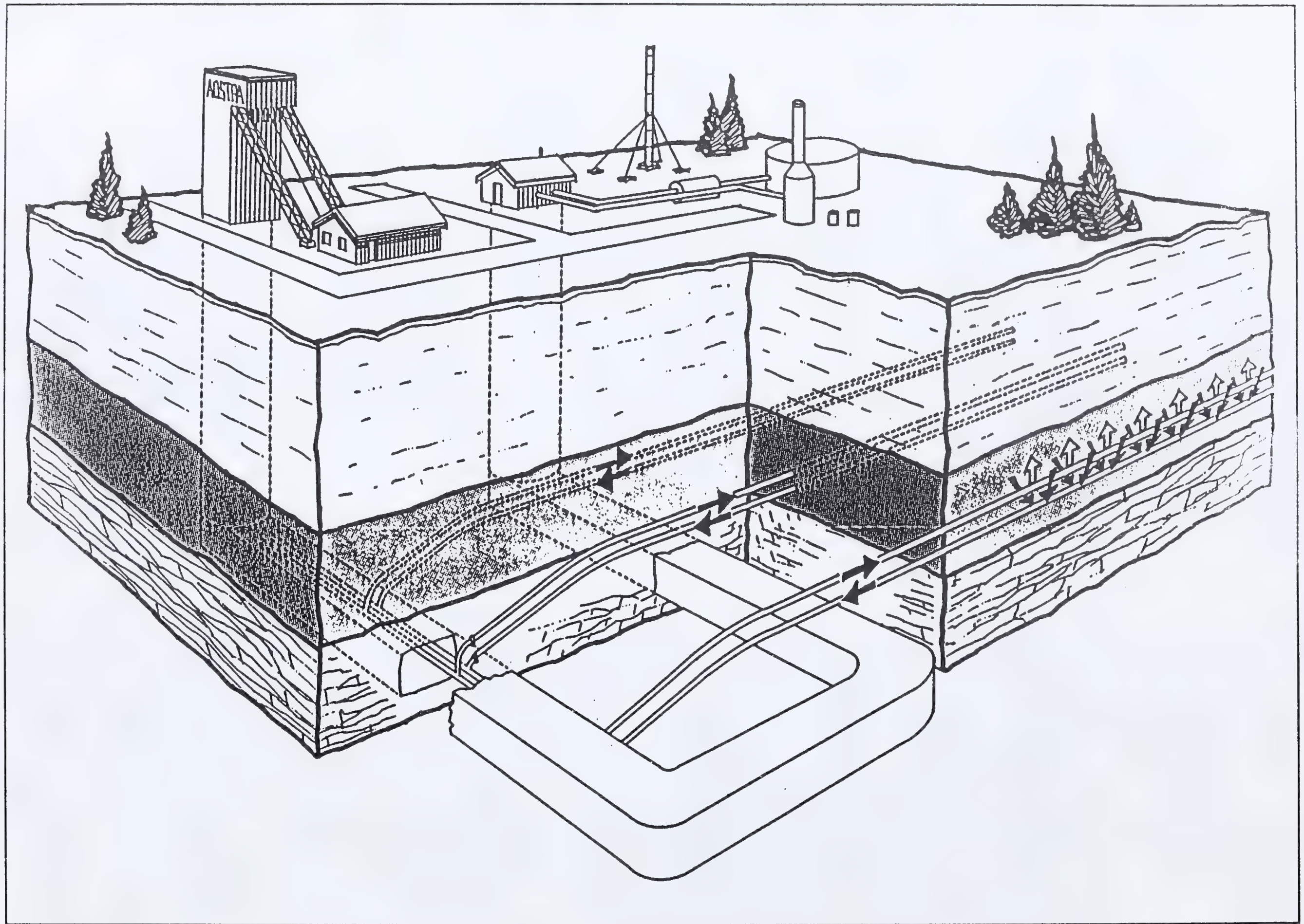
Phase A:	29 wells containing a mix of temperature and geotechnical instrumentation
HASDrive:	6 temperature observation wells

FACILITIES:

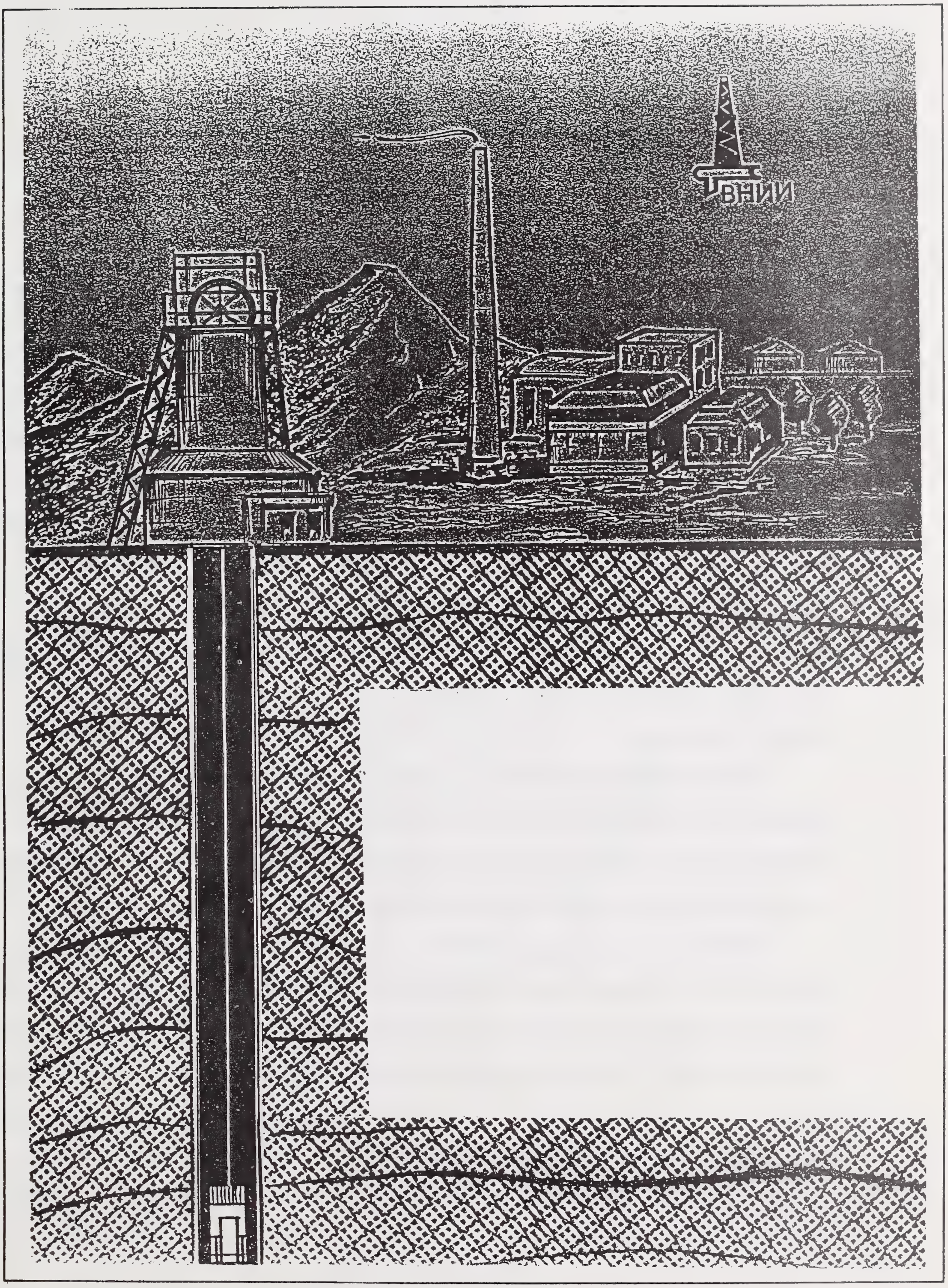
Mine Access:	Two 3–4 m I.D. access shafts 213 m deep; 930 m of tunnel, 5 m wide x 4 m high cross-section; high speed hoist in #1 shaft
Process:	One 7,000,000 BTU/hr steam generator; pumping or steam lift if required; simple gas separation and shipment of produced fluids.

RESERVOIR:

Geological horizon:	McMurray
Depth to top of formation:	135 m.KB
Reservoir thickness:	
– net	22 m
– gross	m
Original temperature:	11°C
Original pressure:	450 kPa
Average horizontal permeability:	4000 md
Average porosity:	35%
Average water saturation – S_w	19%
Average oil saturation – S_o	81% pore volume
Oil viscosity at reservoir temp.	1,000,000 mPa·s
Oil gravity at reservoir temp.	1014 kg/m^3
Primary production rates:	nil m^3/well/day
Source:	AOSTRA



Underground Test Facility



Method of thermal-mine oil fields development

In the USSR, a thermo-mine method is successfully applied in industry for developing the oil fields.

The suggested method allows efficiently to develop high-viscous oil deposits for which a conventional production method (using the wells from the surface) is not profitable.

As a rule, reserves of such crude at the present time are referred to non-recoverable (beyond the balance) reserves.

Good reservoir penetration in case of mine development gives possibility to involve into operation the deposits characterized by not only high viscosity of crudes but by essential heterogeneity of the productive formations too.

Application of this method allows to reach up to 50% and higher oil recovery, that is, to reach the level obtainable under development of low viscous oil fields using traditional methods (water flooding).

Production of oil is carried out without lifting oil-saturated rock to the surface. The depth of oil mines can be the same as that of the coal mines. At the present time, however, the depth of 800 meters is to be considered maximum.

As a results of application of the method, a set of technical operations is worked out for drifting the mine workings in the productive formation, above or under it, drilling of subsurface wells from the mine workings, introducing of heat carrier into the formation, production of oil, gathering and transportation of oil at the conditions of the mine. The methods for prediction of thermal-mine production of oil are developed. In oil mines normal working conditions and safety arrangements are established.

In the USSR transition to new technology in three oil mines allowed to many times increase oil recovery and recoverable oil reserves. When producing oil by the use of the conventional method (by the wells from the surface) oil recovery did not exceed 2%. Extra oil production due to application of the thermal-mine method amounts to about 2 mln.tons.

Estimated calculation shows that in one oil field only a new development method will allow to bring annual oil production of oil of 15 to 20 thous.cp viscosity up to 1-1.5 mln.tons.

Technical decisions are patentable. The patents are obtained: U.S.A. No.4099783, Canada No.1041560.

The licence is offered for the method of thermo-mine development of high-viscous oil fields as a whole, or for its individual components, such as drifting the mine workings in the productive (oil-bearing) formation; drilling the wells from subsurface mine workings; methods for introducing heat carrier into the formation under conditions of oil mines; methods for oil production under subsurface conditions; methods for ventilation of mine workings allowing to create normal working conditions and safety arrangements; methods for prediction of thermo-mine oil production; systems for gathering and transportation of oil in oil mines and know-how as well.

To acquire licences, please address to V/O "Licenzintorg", Moscow 113461, Kahovka street 31. Phone: 122-02-54. Telex-7246. Telegraph: Moscow, Licenzintorg.

RECOVERY OF HYDROCARBONS FROM OIL SANDS AND OIL SHALES BY MINING

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Abstract. The paper defines capabilities of the mining development of heavy-oil, oil-sand and oil-shale fields. The characteristics and reserves of the above-mentioned fields are described. A review of the application of drainage mining development of heavy-oil and bitumen fields in various countries is made. Experience in the thermal-mining development of the Yarega oil field in Komi ASSR in the Soviet Union is described in detail. The methods for producing shales and recovering synthetic oil from them at the surface and by the use of the *in-situ* processes are described. Economic evaluation and the prediction of possible production of hydrocarbons from tar sands and synthetic oil from shales are made. The paper ends with conclusions and practical recommendations.

Résumé. La communication présente les moyens qui existent pour l'exploitation minière des gisements d'huile lourde, de sables asphaltiques et de schistes bitumineux. Elle décrit et passe en revue les techniques minières de drainage employées dans différents pays.

Elle décrit en détail l'expérience obtenue par l'exploitation minière et thermique du gisement soviétique de Yaregskoie (République autonome des Komis). On présente aussi les procédés d'exploitation in situ et ex situ et de transformation d'huile de schistes bitumineux en brut synthétique.

On fait des estimations économiques et des prévisions de production possible d'hydrocarbures à partir de sables asphaltiques et de schistes bitumineux. Enfin on présente des conclusions et des recommandations

1. INTRODUCTION

The prospects of discovering new oilfields throughout the world are more and more associated with the difficult-access areas (deep shelf, permafrost zones, etc.) where oil production costs are many times higher than in the areas with favourable conditions. Therefore, future demand for oil will be met by increased costs. Due to this, factor during the last decade the following major tendencies have received a large development effort.

- Saving of oil and increase in efficiency of its use in all spheres of consumption.
- Enhanced oil recovery in developed fields.
- Production of liquid hydrocarbons from oil sands, oil shales and coal. This has become one of the perspective trends of satisfying the future demand in oil.

2. CHARACTERISTICS AND RESERVES OF HEAVY OIL, BITUMENS AND SHALES

Heavy oil, bitumens and oil shales occupy the lower part of the hydrocarbons' scale (Table I) and possess many common features:

- Completely immobile or slightly mobile in natural state in the reservoirs.
- High content of sulphur, rare elements (vanadium, nickel, etc.), as well as asphalt-resinous components.
- Practically complete absence of gas in reservoirs.
- Density is close to 1000 kg/m^3, whereas viscosity is higher than 1000 mPa sec.
- Effectively produced only by the use of heat or hot agents, i.e. using thermal methods.

Natural bitumens are found in many countries: Canada, Venezuela, USSR, USA, Madagascar,

TABLE I

Scale of densities and viscosities of hydrocarbons

Viscosity (mPa/sec)	Type of hydrocarbons	Density (kg/m^3)
<0.01	Gas	>10
0.3–1.0	Condensate, light crudes	600–700
1–10	Low-viscous crudes	750–850
10–50	Medium-viscous crudes	850–890
50–1000	High-viscous crudes	890–930
1000–20 000	Heavy crudes (75% of oils)*	930–960*
20 000–100 000	Bitumen: malths (40 to 75% of oils)*	960–1000
>100 000	Bitumen: asphalts (25 to 40% of oils)*	1000–1050
plastic	Bitumen: asphaltites (15–25% of oils)*	1050–1100
hard	Oil shales	1000–1100 and more

* The remainder are resinous components.

Albania, Trinidad, Rumania, etc. Thier potential geological reserves throughout the world are estimated in 250 to 300 bln. tons. Recoverable reserves of oil amount to at least 40 bln. tons.

The Athabasca field in Canada is unique having reserves of bitumen (120 bln. tons).

Venezuela possesses the essential resources of heavy oil in the Orinoco Valley (more than 50 bln. tons).

In the USSR the largest reserves of bitumens are found in the Volga–Ural region. In East Siberia essential accumulations of natural bitumens are also known.[1]

The largest reserves of oil shales are concentrated in North America and Brazil. Reserves in the Green River basin, Rocky Mountains, USA, covering the 44 000 km^2 area, exceed 100 bln. tons (in terms of an oil equivalent), whereas the total resources exceed 200 bln. tons.[4,12]

In the USSR the known reserves of oil shales amount to 58 billion tons, whereas potential reserves amount to about 2 trillion tons.[15]

Three principal methods can be applied for the development of heavy oil, bitumen and oil shale deposits:

- Open-pit mining.
- Mining with lifting of rock to the surface (direct mining).
- Drainage mining consisting of the recovery of oil through the wells or the other drainage channels, running from the subsurface mining workings of the oil mine (indirect mining).

3. HISTORY OF PRODUCTION OF HEAVY OIL AND BITUMEN BY MINING

Oil production by mining is an old method and has been used in the following oilfields: Yarega (USSR), Péchelbronn (France), Wietze (West Germany), Campina and Sârata-Monteoru (Romania), Higashiama (Japan).[6]

In the Péchelbronn field over 30 mines of up to 400 m depths were constructed in the 18–19th centuries. Total oil production by mining within a 200 year period amounted to 1.1 mln. tons.[7]

In the Wietze field, West Germany, mining has been used since 1920.[6] In 33 years period of development 765 thousand tons of oil has been produced. Of the total amount of oil produced by mining, 72% was recovered by draining through the mining workings, whereas 26% was obtained by extraction of sand followed by flushing and 2% was recovered by the use of horizontal wells.

Positive results by mining methods through the drainage workings and wells has been obtained in the Sârata-Monteoru field in Romania, since 1930.[8] Annual oil production in 1933 reached 15 800 tons. and attempts to apply the subsurface method of production was made in the other Romanian field (Campina).

Oil production by mining in the Higashiama field (Japan) began in 1940. In 1945 annual oil production had reached 5940 m^3, whereas more than 25.0 thousand tons of oil was produced in total.

Attempts to produce oil by mining has also been made in the oil fields of Australia, Czechoslovakia, Poland and other countries.

Semi-commercial tests mining methods have been carried out in California, Colorado and the other parts of the USA. At present, mining and open-pit mining of bituminous formations are carried out in the 700 hectares area of the Kern River field.

In the heavy-oil Mildred Lake deposit (Canada) the first stage of *in-situ* technology has been completed.[9]

In the USSR mining methods via wells, adits and mines had been carried on since the end of the last century. The depth of the wells have reached 200 m. Initial flow rates of individual wells reached 25 tons of oil per day. In 1915 up to 15 thousand wells were in operation. Maximum oil production from the wells in 1913 amounted to 300 thousand tons.

Production of natural bitumen through adits has been carried out in the USSR from 1913 to 1943 in the Shugurovskoye field in Tataria, where 4 adits and a plant to process tar sand, with a production of up to 500 000 m^3 per year was constructed.

4. PRODUCTION OF HEAVY OIL (BITUMENS) BY THERMAL MINING

The mining–drainage methods of production of heavy oil and bitumens without lifting the rock to the surface requires drilling from the sub-surface mining workings of a large number of wells at 5 to 20 m distance, as the narrow patterns do not permit the effective drainage of high-viscous, heavy-oil formations.

The closer spacing of wells, with the depth of occurrence of the productive formation higher than 100 to 200 m, becomes economically profitable only in case of drilling the wells from the mines.

Figure 1 shows a tendency of decreasing recoverability of oil crude of various viscosities upon widening the well pattern in the case of water flooding and thermal recovery processes. At a high temperature heavy crudes become practically medium and low viscous (10 to 50 mPa/sec), whereas their recoverability upon simultaneous increased density of the well pattern can even exceed recoverability of medium-viscous crudes in case of water flooding. The problem consists of uniform heating of the total volume of the formation.

Figure 1 illustrates that for heavy crudes and bitumens, only dense well patterns (up to 50–100 wells/hectare) have the possibility of reaching uniform heating and a high enough recovery factor (25 to 50%).

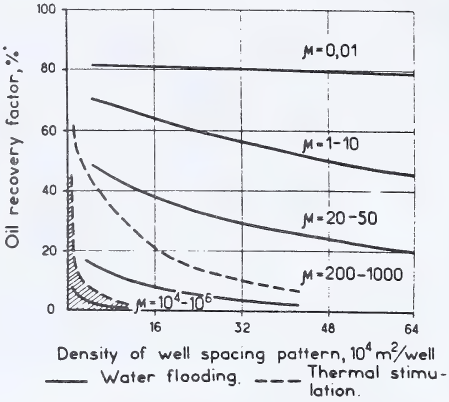

Fig. 1. Recoverability of oil versus a density of well pattern and stimulation method.

Production of heavy oil by drainage thermal mining realized by construction of the mines, drilling of wells from them and thermal stimulation of the reservoir has been practised in the Yarega oilfield (USSR).

The productive formation of this field of 26 m average thickness is represented by quartz sandstone occurring at the depth of 200 m. Permeability varies from 0.5 to 5 m Km^2 (average permeability is 3.17). Temperature ranges from 279 to 281 °K. Porosity is 26°; oil saturation is 87% of the pore volume or 10% by weight. Viscosity of oil varies from 15 000 to 20 000 mPa/sec.; density is 945 kg/m^3.

In the development of this field three major stages are defined.

Pilot development of the area covering 43 hectares through 69 wells drilled from the surface with 70 to 100 m distance between them. The oil recovery factor within 11 years period did not exceed 1.5%.

Drainage mining through the wells due to natural reservoir energy (due to gravitation) without heating the reservoir upon various well patterns, with 12 to 20 m distances between well bottoms and 50 to 200 m length of well bores. The area of about 1500 hectares, where over 115 thousands of wells were drilled, was covered by this technique (Fig. 2).

Development of the oilfield was profitable, but the oil recovery factor for the 18–20 years period was approximately 3%.

From 1968 various methods, of reservoir thermal stimulation were tested in the field. This allowed the creation of effective methods of thermal mining drainage through the wells possessing the following characteristics (Fig. 3).

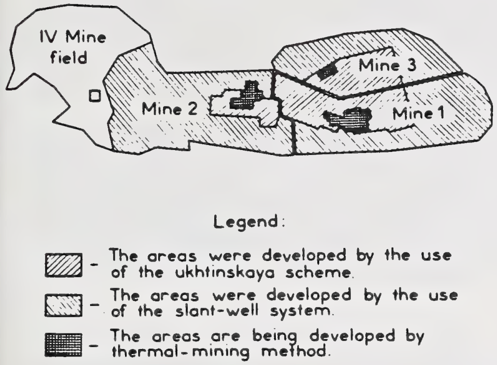
IV Mine field
Mine 3
Mine 2
Mine 1
Legend:
▨ - The areas were developed by the use of the ukhtinskaya scheme.
▨ - The areas were developed by the use of the slant-well system.
■ - The areas are being developed by thermal-mining method.

Fig. 2. Yarega oilfield. Zones of application of various systems.

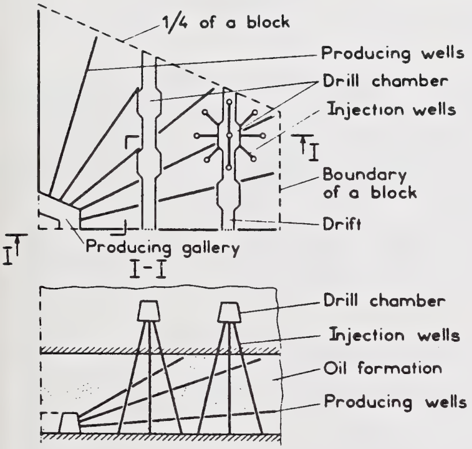

Fig. 3. Yarega oilfield. Scheme of two horizontal systems of thermal-mining development.

(1) In the rock, at a distance of 20 to 30 m above the overlying formation into the bottom of the oil from where slant steam-injection wells are drilled into the oil formation.

(2) The coupled slant workings are drifted from the overlaying formation into the bottom of the oil formation, that are completed by the circular galleries. From these galleries the radial gently-raising producing wells of 100 to 250 m length covering the area of 10 to 15 hectares are drilled.

(3) Cyclic steam injection is carried out into injection wells under 2 to 3 MPa.

In the field other methods of thermal-mining using steam-injection.

5. COMMERCIAL EXPERIENCE IN THERMAL-MINING PRODUCTION OF HEAVY OIL AND BITUMENS

The Yarega oilfield has the widest experience in the commercial application of the thermal-mining development. Three mines have been operated for over ten years.

The area of the deposit covering 225 hectares is under thermal stimulation. This area is produced by 15 slant blocks, where 4192 production wells and 11 795 steam-injection wells are operated. Due to thermal stimulation 2.8 mln. tons of oil are produced. Current reservoir oil recovery of the block under development amounts to 27% of the balance reserves. In two slant blocks, which have been operated for about 8 years, oil recovery amounting to 50% has been reached. These areas continue to produce oil.

Specific consumption of steam has dropped from original 5.5 t/t to 2.74 t/t, whereas in individual areas of the oil mine No. 1 it has dropped to 2 t/t.

At present, 3.3 thousand tons of steam are injected daily into the reservoir and 1.2 thousand tons of oil are produced.

In 1981 production of oil by thermal mining amounted to 415 thousand tons (Fig. 4). This is planned to be increased to 1.6 mln. tons after reconstruction of the existing mines and putting 3 new high-mechanized mines into operation. Unit capital costs of oil production by thermal-mining are half that of coal production by mining in terms of equivalent fuel.

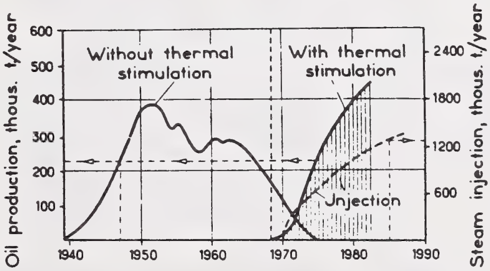

Fig. 4. Yarega oilfield. Dynamics of oil production by mining and steam injection.

Mining methods, may, find an application in the pro-production from offshore oilfields. In this case mine shafts can be located in the onshore or in the islands (artificial or natural), whereas the adits will be located under the sea bottom.

During recent years a number of projects of oil production through adits has been discussed.[10] Some of them provide the possibility of development of hydrocarbon fields located at 25 to 30 km distances from the shore.

In the USSR technical designs on the construction of the off-shore oil mines in the Caspian sea have been devised.

Currently, the largest projects of producing tar sands are carried out in Canada. In Athabasca, two large projects of the open-pit mining and thermal-caustic processing of tar sands have been realized producing 10 mln. tons/year of synthetic oil.

The other large projects applying open-pit mining and *in-situ* technology of bitumen recovery in Athabasca are at the planning stages.

It is estimated that by the end of 1990s up to 50 mln. tons of synthetic oil will be produced from tar sands.

At present in Alberta province approximately 15 pilot-commerical tests on various *in-situ* technologies of development of tar sands are being conducted.

Oil production by thermal mining in the Kern River oilfield in California is shown in Fig. 5.[14].

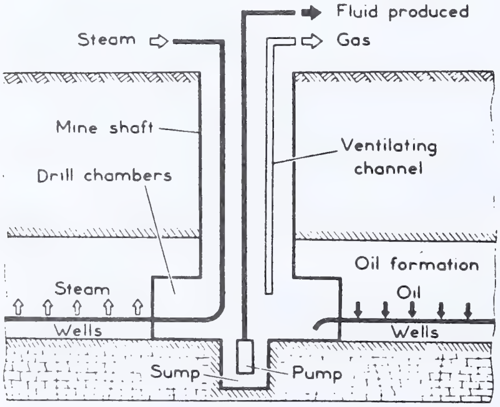

Fig. 5. Scheme of the project of thermal-mining production of oil (Hop Corporation).

In the USSR programme of recovering oil from tar sands has been developed and field testing of the *in-situ* technologies by the use of wells drilled from the surface (injection of steam and *in-situ* combustion) is being carried out.

Development of tar sands by the use of the *in-situ* mining method at 75 to 100 $\$/m^3$ expenditures for bituminous oil production appears to be quite reasonable.

Disadvantages of the mining and thermal-mining technologies are that in all stages of its development personnel have to work under subsurface conditions. Automation of the process cannot completely exclude this necessity.

Consequently, high costs for ventilation of the subsurface mining workings are required. Special measures on excluding the possibility of an explosible situation in the mine should be provided. Costs for such measures can reach 15 to 20% of the total oil production costs.

6. DEVELOPMENT OF OIL SHALE BY MINING—RECOVERY OF HYDROCARBONS AT THE SURFACE

Oil shales (as a fuel) were for the first time commercially used in the middle of 19th century in France and later in other countries (USSR, Scotland, Canada, Austria, USA, Brazil, Switzerland and Spain).

The main trend for the commerical use of oil shales at the present time is the recovery of valuable hydrocarbons, i.e. oil and gas through thermal decomposition of shales at a temperature of 450 to 550 °C, as well as by the use of pyrolysis and retorting processes.

The yield and quality of valuable hydrocarbons recovered from oil shales depend on the properties of shales and, mostly, on the conditions of their thermal decomposition (pressure; consumption of air, gas, steam; addition of hydrogen; size of shale pieces, etc.).[11] The pyrolysis of shales can be conducted in special retorts, constructed on the surface, or *in situ*. The pyrolysis of shales at the surface, naturally, requires production by mining and preparation for a full-volume retorting. The *in-situ* process of pyrolysis requires essentially a lower volume of shale recovered by mining (not more than 20 to 25%).

The thermal decomposition of shales is carried out through heating, either by the burning of a part of shales in the retort (direct retorting), or by their contact with a gaseous or hard heat carrier (gas, steam, ceramic balls, residual ash) (indirect retorting).

Currently, over ten surface retorting processes with different conditions of heating oil shales are known and tested to a various extent.

Any well-known retorting process requires preparation of the oil shale, i.e. crushing it into pieces of a size not less than 4 to 5 cm, as well as sorting it by fractions.

In retorts Galoter (USSR), Tosco (USA) and Lurgi (West Germany) a hard heat carrier is used, whereas in retorts Petrosix (Brazil) and Union (USA) burning gas is applied as a carrier. In retorts Kiviter (USSR) gas combustion products are used and in those of Paraho, Superior and Union (USA) the process of combustion of solid residue (direct) (Fig. 6), or with an additional supply of burning gas (indirect) is applied.[11] The retorts working with hard heat carrier require fine crushing of shale (less than 1–2 cm). In the retorts, operating on the direct pyrolysis principle, i.e. on the principle of combustion, large pieces of shale are used (up to 4–10 cm).

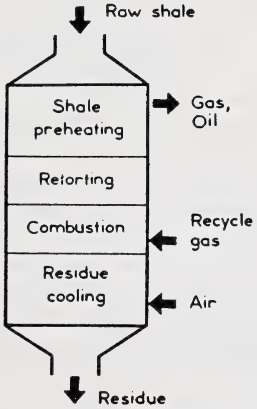

Fig. 6. The Paraho process of the retorting of oil shale at the surface.

All these surface retorting processes are potentially commercial but the Galoter, Kiviter, Petrosix, Union and Tosco processes are of the highest productivity (more than 1000 tons of shale per day). The remainder are semi-commercial (productivities of Paraho, Superior and Lurgy are 225 tons/day, 225 tons/day, 11 tons/day, respectively).

7. THE *IN-SITU* PROCESSES OF RECOVERING HYDROCARBONS FROM OIL SHALES

Complexity of thermal decomposition of oil shale in the retorts at the surface, high costs of production, crushing and transportation of the rock, as well as an environment protection problem, gave birth to the idea of the *in-situ* retorting process.

In-situ methods also require crushing of the shales or creation of intensive artificial fracturing in the reservoir.

To heat the reservoir to a temperature of 450 to 550 °C the internal (*in-situ* combustion) or external sources of heat (injection of hot agents, such as steam or air) can be used. Both these processes are real in a technical sense, but their efficiency depends on the degree of oil shale crushing and artificially created communication between the points of injection of the working agent, and the points of withdrawal of the reaction product throughout the oil shale formation.

To make artificial fracturing in oil shales various methods were tested, including reservoir fracturing followed by detonation of the injected liquid and granular hard explosives in the reservoir, as well as electrical breakdown, thermal cracking and nuclear explosions.

Several *in-situ* processes of oil shale retorting are well known: Occidental, Multi Mineral, Geokinetics, Iquity and others. However, only the first two are associated with oil shale production by mining. Using the Occidental method, 20 to 40% of shale is recovered from the bottom of the future subsurface retort by mining, that is used in the retorts at the surface. From the cavity formed, the vertical wells at the depth of 30 to 45 m are drilled. By the use of the latter, blasting of the productive formation is carried out. After the explosion the cavity is found to be filled with the crushed shale and can be used as the subsurface retort. Fuel (gas) and air are injected into the upper part of the cavity and the combustion process is initiated. The front of combustion moves downward. The product of the kerogen processing flows to the lower part of the cavity, from where it can be taken together with the gaseous products to the surface (Fig. 7). Oil recovery is low, and the gas quality is poor. Various modifications of this process

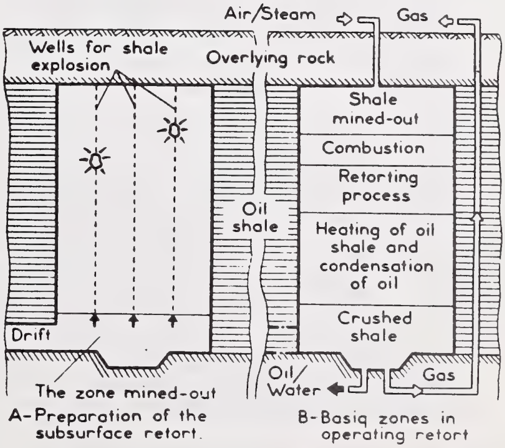
Air/Steam
Gas
Wells for shale explosion
Overlying rock
Shale mined-out
Combustion
Retorting process
Oil shale
Heating of oil shale and condensation of oil
Crushed shale
Drift
The zone mined-out
Oil/Water
Gas
A-Preparation of the subsurface retort.
B-Basiq zones in operating retort

Fig. 7. The Occidental process of the *in-situ* retorting of oil shale.

are available. The Multi-Mineral process is carried out in three stages. Apart from the recovery of liquid hydrocarbons from oil shales in the vertical subsurface retort (stage II), this process provides preliminary recovery of useful components such as Dawsonite and Nachkolite (stage I). After retorting, soda ash and alumina are leached from residual ash (stage III).

The Geokinetics process uses a horizontal subsurface retort in shallow formations through the preliminary crushing of oil shale by explosions carried out in the wells drilled from the surface (Fig. 8).

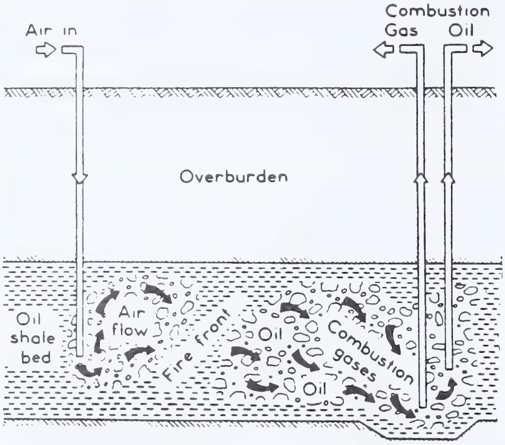

Fig. 8. Geokinetics process subsurface retorting.

Through injection wells the combustion process is initiated in the formation. Due to injection of air and steam the combustion front moves horizontally. Oil and gas are recovered through producers. Recovery of up to 50% of oil from oil shale is supposed.

The Iquity process is intended for the development of oil shales contained in carbonate porous, permeable rock without mining and crushing the shales. This method provides injection of overheated steam into the oil shale formation through injection wells, removal of sodium bicarbonate by leaching, injection of hot gas or steam at a temperature of up to 400 °C and pressure up to 10 MPa and recovery of hydrocarbons through producing wells.

8. COMMERCIAL PROJECTS AND EFFICIENCY OF RECOVERING HYDROCARBONS FROM OIL SHALES

Results of semi-commercial tests has shown the capability of recovering liquid hydrocarbons from oil shales, both by retorting at the surface and by the use of the *in-situ* pyrolysis. The most active technology is conducted in the USA. Costs of 1 ton of oil during the semi-commercial tests varied from 90 to 220$. At present, about 80 000 tons of synthetic oil has been produced in surface and subsurface retorts by various companies using different processes. Of these, over 20 thousand tons of oil are produced by Paraho Co. and 45 thousand tons by Occidental Oil Shale Co.

Paraho carried out a demonstration programme of testing various retorting technologies in vertical retorts. Occidental conducted eight tests of shale retorting in the subsurface retorts of various sizes from 2400 m^3 up to 260 000 m^3. In each of three last retorts 300 to 350 thousand tons of oil shales were subjected to thermal decomposition.

At present, more than 20 large projects of oil shale retorting are being prepared for commercialization in 1986–1990 with the use of various technologies. Of them, more than 10 projects will be realized in the USA.

Some of these projects are illustrated in Table II.

When these projects are commercialized, production of synthetic oil from oil shales would reach 40 to 45 mln. tons in 1990, including 25 to 28 mln. tons in the USA. A full design output of the existing projects exceeds 52 mln. tons/year.

The *in-situ* retorting projects provide only 9 mln. tons/year or 17%, whereas the rest 83% are provided by the surface retorts with gaseous (68%) and hard (15%) hear carrier.

In perspective, before 2000 various rates of oil production from oil shales are possible: from 30–80 mln. tons/year (minimum) to 200–250 mln. tons/year (extreme) depending on economic conditions and the completion of retorting technologies.

According to the US fuel-energy prediction for 2000, the maximum variant assumes that synthetic oil and gas produced from oil shales and coal will amount to 12% of the total consumption of energy.[13]

Brazil, having oil shale reserves amounting to more than 120 bln. tons in terms of an oil equivalent, possesses essential capabilities of producing synthetic oil from oil shales. In this country the Petrosix unit of 50 000 tons of synthetic oil per year capacity is already in operation.

In the USSR at present 28 million tons of shale per year is burnt at the electric power stations in Estonia. This results in releasing over 5 million tons of equivalent oil per year intended for the other purposes. Besides this, some amount of shales is subjected to thermal processing with the use of two *ex-situ* technologies (Galoter and Kiviter).

TABLE II

The largest projects of the retorting of oil shale

Project (country)	Process	Production goals mln.t/year
Parachute Creek (USA)	Union	0.5 (1983)
		5–7 (later on)
Rio Blanco (USA)	Occidental, Lurgi	2.5 (1991)
White River (USA)	Paraho, Superior	0.7 (1985)
		5.0 (later on)
Pacific (USA)	Superior	0.75 (1985)
		5.0 (later on)
Sand Wash	Tosco	2.5 (1988)
Petrobras (Brazil)	Petrosix	2.5 (1988)
Parana (Australia)	Superior, Lurgi	3.0 (1990)
Alexinac (Yugoslavia)	—	1.2

At present annual world production of liquid synthetic fuel from oil shales (shaly resin) amounts to more than 1.0 million tons, greater part of which is in the USSR.[15]

Technological and economic efficiency of hydrocarbon recovery from oil shales varies within a wide range depending on the properties of shales and the process applied.

In all predictions it is supposed that recovery of liquid hydrocarbons from oil shales accounts in average for 5–10% by weight. In pilot processes, this value varies from 3%, in the first tests with the Occidental *in-situ* technology, to 15–18% with the Kiviter technology applied for rich Baltic oil shales.

Application of retorting processes the hydrocarbons recovery from oil shales can reach not more than 50% of kerogene initially in place.

The cost of synthetic liquid fuel produced from oil shales ranges from 40–50 to 200–220$/ton.[15]

9. CONCLUSIONS

Heavy oil, tar sands and oil shales are considered to be an important alternative reserve for production of hydrocarbon fuel.

Huge reserves of heavy oil, tar sands and oil shales in Canada, USA, Venezuela, USSR, Brazil and other countries allow the future planning of large-scale production of synthetic liquid fuels, with reserves as reliable alternative sources of oil.

Many processes of recovering these types of hydrocarbons have been tested and the technological and economic results can be considered satisfactory.

In future the major developments of tar sands, heavy oil and oil shales will be, by surface mining and processing, together with various thermal-mining *in-situ* drainage processes.

The prospects of recovering hydrocarbons from tar sands and oil shales raise environmental protection problems, especially the problems of water requirements for the processes and the protection of aquifers.

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Chapter 30

PRACTICAL ASPECTS OF RECOVERING HEAVY CRUDE, BITUMEN AND OIL SHALE

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As numerous evaluations show, resources of heavy ude, tar sands and oil shale in the world are significantly rger than resources of conventional oil. However, efficient ofitable commercial technology for the recovery of avy crude and hydrocarbons from tar sands and oil shale as not yet been developed, whereas potential reserves of is type of fuel are hardly used. Heavy crude, tar sands and l shale occupy the lower part of the hydrocarbons scale, if ey are located in the order of increasing density and scosity.

Natural deposits of heavy crude, tar sands and oil shale ossess many common features:

- Rock (reservoir) in initial state, without any stimulation, is practically impermeable.
- Hydrocarbons in these deposits in natural state are completely immobile or a very small volume of them is mobile.
- These deposits have a high content of sulphur and rare elements (vanadium, nickel, etc.) as well as asphalt-resinous components.
- There is an almost total absence of gas in the reservoirs.
- The density of the hydrocarbons is close to 1 (0.97–1.05), whereas viscosity is from 10 to 20 thousand cp., i.e., this is solid substance.

These deposits can be effectively developed only by ing heat or hot agents, that is, by thermal methods. Four fferent thermal methods can be applied to develop avy crude, tar sand and oil shale deposits:

- Open-pit mining, followed by hot-agent processing of the rock in the plant.
- Mine development, with rock lifted to the surface and processed by hot agent.
- Well-drainage, consisting of drilling wells from the surface and of producing oil from the wells via injection of hot agent from the surface to the reservoir.
- Mine-well drainage, consisting of the construction of the mine as far as the reservoir and then drilling the wells, production of oil, and the injection of hot agent from the mine.

If there were no restrictions in terms of capital investment and the environment, the method based on lifting reservoir rock with all its contents to the surface probably would be the most prospective because it allows production of 75–95 percent of original reserves of heavy crude and hydrocarbons from tar sands and oil shale.

As experience shows, however, pit development is economically profitable with the depths not greater than 50 to 60 meters. The mine method of lifting rock containing only 7–10 percent by weight of crude to the surface is even less profitable than production of low-calorific coal. The necessity of using large volumes of water (5 to 8 cu m per ton of rock) to process the rock on the surface plus the requirements for environmental protection, results in raising the profitability threshold of pit or mine development, followed by lifting of oil-bearing, bituminous, and shale rock to the surface, to a marginal level.

The essential, even the basic part of the known reserves of heavy crude, tar sands, and oil shale lies at depths of 100 to 600 meters. At these depths only the methods of development with the help of wells or by the use of mines and wells, without lifting the rock to the surface, or the so-called in-situ technology, can be applied. The in-situ technology applied for recovering heavy crude, bitumen, and oil shale with the use of either wells and mines together, or wells alone, was developed over a long period of time (more than 20–25 years) in various countries, for instance, in the U.S.S.R., the U.S.A., Canada, and Venezuela. But the technology applied for thermal mining of heavy crude has progressed toward commercial application only in the Soviet Union.

The technology for recovering heavy crudes, bitumen, and oil shale by the use of wells drilled from the surface of the earth to the deposit, in the near future, will probably also be developed, tested, and prepared for commercial application. The basic difficulty in this technology consists in distributing heat, introduced into the reservoir, along the total volume of heavy crude, bitumen, and shale oil, decreasing their viscosity and making them mobile. The methods for heat distribution along the volume of heavy crude, bitumen, and oil shale deposits can apparently be identical, based on the formation of directed fractures and splits or through adjacent water-bearing layers. However, to reach uniform warming-up of the deposits using such methods,

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U.S.S.R. State Committee for Science and Technology, Moscow

**All-Union Scientific-Research Oil and Gas Institute, Moscow* the distances between the wells should be rather small in all cases.

The experience of oil field development using water flood shows that when reservoir heterogeneity and viscosity ratios displaced oil to displacing water increase, the necessity to increase the well spacing pattern rises sharply. In terrigenous reservoirs where the ratio of maximum permeability to the average is 4:5 and the ratio of oil viscosity to water viscosity is 1:3 the process of development of oil deposits quite effectively proceeds with well spacing density up to 35–50 hectares per well; the oil recovery factor reaches 40 to 60 percent. Gas deposits, as it is known, are developed even with well spacing density up to 500–600 hectares per well and 70 to 80 percent recovery of gas reserves. In reservoirs of the same heterogeneity but with oil viscosity higher than 100–20 cp reservoir oil recovery higher than 15 to 20 percent cannot be reached even with 2 to 4 hectares per well density of well spacing and water flooding. This absolutely definite tendency towards decreasing reservoir oil recovery in case of increase in oil viscosity is explained by the following reasons. In the process of displacing low-viscosity oil by water, heterogeneity of fluid flows is determined basically by the permeability ratio of the flooded and oil saturated intervals, which usually does not exceed 4:5, whereas in the process of displacing high-viscosity oil by water, heterogeneity of fluid flows is caused by mobility ratios (K) of the flooded and oil saturated layers of the reservoir. At first this ratio is also 4:5, whereas by the moment of water breakthrough into the wells the latter reaches 250:500 and higher. Due to this, the process of development proceeds with high water production. The limit of economic profitability for producing wells is reached at low ultimate reservoir oil recovery.

In case of thermal stimulation of the reservoirs, where heterogeneity of the flows and conductivity is high, oil cannot be effectively warmed-up; its mobility therefore cannot be increased when the distance between the injection and producing wells is large because velocity of the displacement front along the layers is 4 to 5 times higher than that of heat transfer, whereas convective heat transfer along layers is considerably higher than interlayer warming-up due to heat conductivity.

In case of development of heavy crude, tar sand, and oil shale deposits using the well-drainage method, when a limited number or even individual fractures are formed between the wells, the warming-up process can proceed only through fractures due to heat conductivity. This process will be slow and uncontrolled at large distances from injection wells. Thus, there is no doubt that to apply the well-drainage method for recovering heavy crude, bitumen, and oil shale, quite dense well spacing (possibly less than 10 to 15 meters) will be required. The warm-up of heavy crude, bitumen, and oil shale is possible not only with the use of artificially-created fractures in the reservoirs but also through water saturated adjacent zones by means of thermal-agent injection. With this, efficiency of the warm-up will be not higher than in the previous case. There is a tendency to decreasing recoverability of crudes at various viscosities in case of widening the well spacing when applying water flood and a tendency to increasing recoverability of highly viscous and heavy crudes when applying thermal stimulation. When temperature increases, heavy crudes become, practically, medium- and low-viscosity crudes (10 to 25 cp). Their recoverability can, with simultaneous tightening of well spacing even exceed recoverability of medium-viscous crudes in case of water flood.

This principal conclusion made for the well-drainage method of recovering heavy crude, bitumen and oil shale entails a natural question: is it possible in practice to realize effectively a well spacing of such high density? The clear answer to this question can be given only by the economic analysis of the real indices of the process of hydrocarbon recovery for each specific heavy crude, tar sands, and oil shale field.

However, one can expect that, with certain depths of heavy crude, tar sands, and oil shale occurrence and specific geological and physical conditions the mine-well, the drainage method will be more effective than development using the system of the wells drilled from the surface. Using one productive mine and one open pit, the area of a deposit o up to 50–75 hectares size can be stimulated. To warm-up effectively the reservoir of such an area, 45,000 to 75,000 wells will be required. It is quite possible that when the depth of reservoir occurrence is high, the total expense fo construction of two shafts for the mines, with all subsurface service lines, will appear considerably less than expense for drilling such a large number of wells from the surface to the reservoir and for the work on well completion on the surface. If one will take into account essential heat losses in injection wells, which practically can be eliminated by feeding heat through mines, as well as simplification o lifting fluids from the mines as compared with producing a large number of wells, then the mine-well drainage method for recovering heavy crude, bitumen and oil shale can be in many cases more preferable economically than conventional well-drainage technology.

The general equation of the efficiency of the mine-wel drainage method for recovering heavy crude, bitumen, and oil shale can be represented as follows:

$$C_m + C_h \cdot N + E_m \leqslant (C_w + E_w) \cdot NA$$

where:

C_m = total expenses for construction of the mine and subsurface service lines.

C_h = expenses for drilling and well completion with in the limits of the productive reservoir.

E_m = operating expenses for the mines and well

C_w = expenses for drilling the well from the surfac and its completion.

E_w = experimental expenses per one well.

N = number of wells in the area covered by th mine.

A = coefficient taking into account heat losses the wells depending on the depth; it can reac 1-1.3.

The Yaregskoye oil field (U.S.S.R.) can serve as an example of effective development of the heavy crude deposit using the mine-well drainage method. The productive reservoir of this field lies at a depth of 200 m. It is represented by fractured sandstones of 3 darcy average permeability, and thickness of 17 meters, 7 percent (by weight) oil saturation. Crude is of 1.5 to 2×10^4 cp viscosity, 0.94 to 0.95 gravity. Original reservoir pressure is 14 to 15 atmospheres, reservoir temperature 15° C to 8° C. Development of this field was conducted using three different methods in three stages.

The well-drainage method was applied from the very beginning of development and consisted in drilling the wells from the surface over an area of 43 hectares at distance of 70 to 100 m with 0.5 to 1 hectare/well spacing. In case of producing the wells under natural depletion drive the well production rates decreased below the limiting value over six years. Reservoir oil recovery factor did not exceed 2 percent of initial geological reserves (oil in-place).

The mine-well method of development was applied without thermal reservoir stimulation in the other areas of the field. The oil-bearing reservoir is drilled by two mine shafts. The productive (lifting) shaft serves for lifting and lowering the people, equipment, materials, etc. The vent shaft is designed for ventilating the mine workings, drifts, pit bottom, and the other subsurface constructions.

The wells were drilled from the subsurface mine workings into the productive formation using two systems: the system of vertical wells 50 m deep at the distance of 12 to 20 m, drilled from workings above the formation and the system of inclined wells of up to 300 meters length at the same distance, drilled from workings above the formation.

In the various areas, with the use of wells and without thermal stimulation, the mine fields were exploited for 14 to 20 years. Oil recovery reached in the fully depleted areas was only 6 percent of initial reserves. The problem of complete closing of the mines and stopping development of the field was faced.

Since 1970 use has been made of the existing mines and wells in two areas to conduct reservoir thermal stimulation with application of steam injection. Reservoir temperature raised to 100° C and higher, whereas crude viscosity dropped from 15,000-20,000 cp to 25-30 cp. During 2.5 to 3 years in an area of 12 to 15 hectares, average daily production of oil rose to 200 tons whereas ultimate oil production reached 127,000 tons. Unit steam consumption dropped from 5.5-6 t/t to 2-2.8 tons per ton of produced oil, whereas prime cost of oil decreased two times. Evaluation of ultimate reservoir oil recovery showed that it reaches 57 to 58 percent of initial geological oil reserves (oil in-place).

At the present time three productive mines are operating in the field, covering an area of more than 190 hectares. Oil production exceeds 600,000 tons per year. This is supposed to be increased to one million tons per year after putting a new mine into operation. Unit capital investment in oil production using the thermal mining method is half the investment for coal production (using the mining method), evaluated in equivalent fuel. To produce one ton of oil the following is required: drive approximately 0.04 m of mine working; drill 0.5 m of subsurface wells; use 3.5 tons of steam, including 2.5 tons for reservoir warm-up; and apply 98 kwh of electric energy, and 282 cu m of compressed air.

The ten-year experience of commercial application of thermal mining of heavy crude in the Yaregskoye oil field permitted development of:

- methods of driving the mine shafts and mining workings in various positions in relation to the productive formation;
- technology for drilling subsurface wells of up to 300 m in the mines;
- special equipment for drilling vertical and inclined wells in the mines;
- means for reliable ventilation of mining workings, allowing to provide normal conditions for the staff;
- technology for introducing heat carrier into the reservoir, allowing its most effective use;
- technology for oil production that essentially simplifies producing the wells;
- methods for prediction of oil production using the thermal mining method;
- system of gathering and transporting oil under conditions of oil mines; and
- measures securing safety for the staff.

On the basis of generalization of the experience in recovering heavy crude, bitumen, and oil shale in various fields, as well as from conducting research work, approximate criteria for applicability of various methods of field development (table 30-1) can be defined. Thus, the thermal-mining, well-drainage method of development of heavy oil deposits as worked out and applied in the Soviet Union can find, in the future, wide application in practice and become in technological and economic respects one of the most effective methods applied for recovering bitumen and oil shale.

Technical and economic problems of putting the tarry oil resources into effective development are paid a great attention in all countries where these resources have been discovered, in Canada, the U.S.A., and Venezuela in particular. These problems are also real in the Soviet Union, where considerable tar resources are available in the Ukraine, Azerbaijan, the Volga-Urals region, Kazakhstan, the Komi ASSR, and Eastern Siberia.

The tar deposits located in the regions with a developed materials and technical base for oil production and processing, and proper infrastructure, are, of course, of most immediate interest. These conditions, for example, are met by natural bitumen accumulations located within Tataria (during the last 38 years two billion tons of oil have been produced from the deposits of this Autonomous Republic) and the adjacent Kuibyshev and Ulyanovsk regions. Here, as early as the 18th century, tar indications were observed on the surface; however, purposeful efforts in the study of commercial tar production were undertaken a comparatively short time ago.

Table 30-1. *Criteria for applicability of various methods of producing heavy crude, bitumen, and oil shale*

1	2	3	4	5
Criterion	Open-pit method	Mine (lifting) method	Well-drainage method	Mine-well drainage method
1. Depth (m)	0 to 60	50 to 100	100 to 800	100 to 800
2. Reservoir thickness (m)	5	10	10	10
3. Saturation (% by weight)	7	10	7 to 12	10
4. Reservoir permeability (darcy)	makes no difference	makes no difference	1	1
5. Fracturing	makes no difference	makes no difference	favourable	favourable
6. Reservoir firmness	friable	friable	firm	firm
7. Pressure (atm)	makes no difference	10	favourable	20
8. Hydrocarbon viscosity (cp)	10^6	10^6	–	10^4
9. Gas saturation (cu m/cu m)	makes no difference	15	favourable	15
10. Temperature (°C)	makes no difference	35	favourable	36

At the present time, the required geological activity has been carried out; 690 special wells and 1250 structural wells have been drilled which revealed 80 tar fields in Permian sediments. Of these fields, 21 are already explored in detail. About 80 percent of tar reserves are associated with carbonate reservoirs; the 20 percent with terrigenous reservoirs are within the essentially negative structure of the highest order, i.e., the Melekesskaya Depression and adjacent bordering slopes of South and North Domes of the Tatarsky and Tokmovsky Archs.

The study of properties of the tars for commodity purposes showed that they are potential raw material for manufacturing motor fuels, lubricating oils and some other initial products for the petrochemical industry, as well as for paving and building tars. Fuels for diesel motors obtained from natural tars meet the strict requirements to arctic types of fuels without additional deparaffinization, whereas by content of oil fractions several tars are even better than crude oil used for manufacturing lubricating materials. Besides this, tars very often contain vanadium, nickel, and some other rare metals in concentrations that are of commercial interest.

At present, various technological schemes are under evaluation for tar processing, mainly to produce motor fuels (yield up to 58 percent), fuel for boilers and furnaces (59 percent), initial products for petrochemical industry (36 percent), and building and paving bitumen (72 percent). In principle, any of these schemes can be realized with oil-processing equipment operating in our country. However, with a large-scale production configuration for bitumen production and processing, equipment will be essentially predetermined by its orientation to the manufacturing of the final products. An optimum combination of technical means for recovery and processing the bituminous raw material, being combined into a practically new branch of industry, should provide high profitability for the whole production cycle. Creation of such a branch of industry is a task of essential economic importance for the national economy. The Soviet Union possesses the required scientific and technical potential as well as resources for a timely and successful resolution of this task.

At the same time, it is quite evident that the countries interested in exploitation of natural tar resources could choose the way of scientific-technical and commercial-economic cooperation aimed at quicker and more economic resolutions of common problems connected with drawing this prospective source of hydrocarbons into the economy.

The tar accumulations occur at depths of up to 400 m in reservoirs of permeability that ranges from hundreds of fractions to 0.5 mKm^2, porosity from 10 to 48 percent, and bitumen content from 10 to 98 percent by volume of pore space. It appeared possible to divide these deposits into groups with 1 to 3 percent, 3 to 5 percent and higher than 5 percent by volume of rock, according to bitumen content (by weight) in the enclosing rock. Fifteen percent of all geological reserves falls in the first group, 64 percent in the second, and 21 percent in the third. In total, the tar resources of Melekessky Basin are estimated to be about 19 billion tons, of which 7.0 to 9.0 billion tons are concentrated in Tataria. Of these, 1.5 billion tons are of more than 5 percent bitumen content by volume.

The Tartarian Permian tars are oxidized, highly viscous, of high sulphur content, and almost completely free of light fractions. By their consistency and composition they are very heterogeneous, about 85 percent of their volume represented by high-viscous oils and maltha, the rest by asphalts and asphaltenes. The tar density ranges from 0.93 to 1.026 g/cm^3, viscosity ranges from 1 Pa·s to 1 mPa·s. The elemental composition is: carbon 80 to 84 percent, hydrogen 10 to 12.6 percent, sulphur 3.5 to 8 percent, nitrogen and oxygen, less than 1 percent. The group composition according to the Markusson method is: asphaltenes 5 to 35 percent, resins 12 to 60 percent, oils 20 to 70 percent, paraffins usually less than 1 percent. Yield of fractions boiled out at temperatures up to 200° C from the lightest tars does not exceed 5 percent. Solidification temperature is -12 to 26° C.

The method of bitumen production is to be defined for each field, proceeding basically from reservoir properties and depth, as well as from physico-chemical characteristics of formation fluids. According to the results of laboratory experiments, and taking into account reservoir models developed on their basis, a number of methods of tar production have been recommended for field testing. Thus, in the Sugushlinsk deposit in Tataria, pilot-commercial injection of steam, sulphuric acid, solvents, in-situ combustion, reservoir stimulation by hydroabrasive material, and high-frequency electric currents have been tested, whereas in the Mordovo-Karmalsky field in-situ combustion (South dome) and steam recovery (North dome) have been performed. As a result, the possibility of commercial production of liquid bitumen by the use of thermal methods and solvents has been confirmed and thermal recovery was found to be more effective.

Along with this, it appears evident that traditional technology of oil field development by the use of wells requires modification applicable to peculiarities of tarry oil production. In particular, the transition to commercial tar production and for well-bottom stimulation; development of special well design; and resolution of problems of demulsification, transportation, waste water purification, etc. After resolving these problems as required, 12 fields, prepared for production, will be put into exploitation using an in-situ combustion method; eight of these are candidates for development by steam injection. In 1985, bitumen production in Tataria will be brought to tens of thousands of tons per year.

In such a manner, only the liquid bitumen deposits located in highly permeable reservoirs will be developed; these account for 30 percent of total geological tar reserves in Tataria. Recovery factor is estimated to be 0.2 to 0.3. The approximate calculations show that the prime cost of one ton of bitumen obtained using steam injection will amount to $34.30 (24 roub) with 50 × 50 m well spacing and $25.70 (18 roub) using 100 × 100 m spacing. For in-situ combustion these indices will be $33 (23 roub) and $23 (16 roub), respectively.

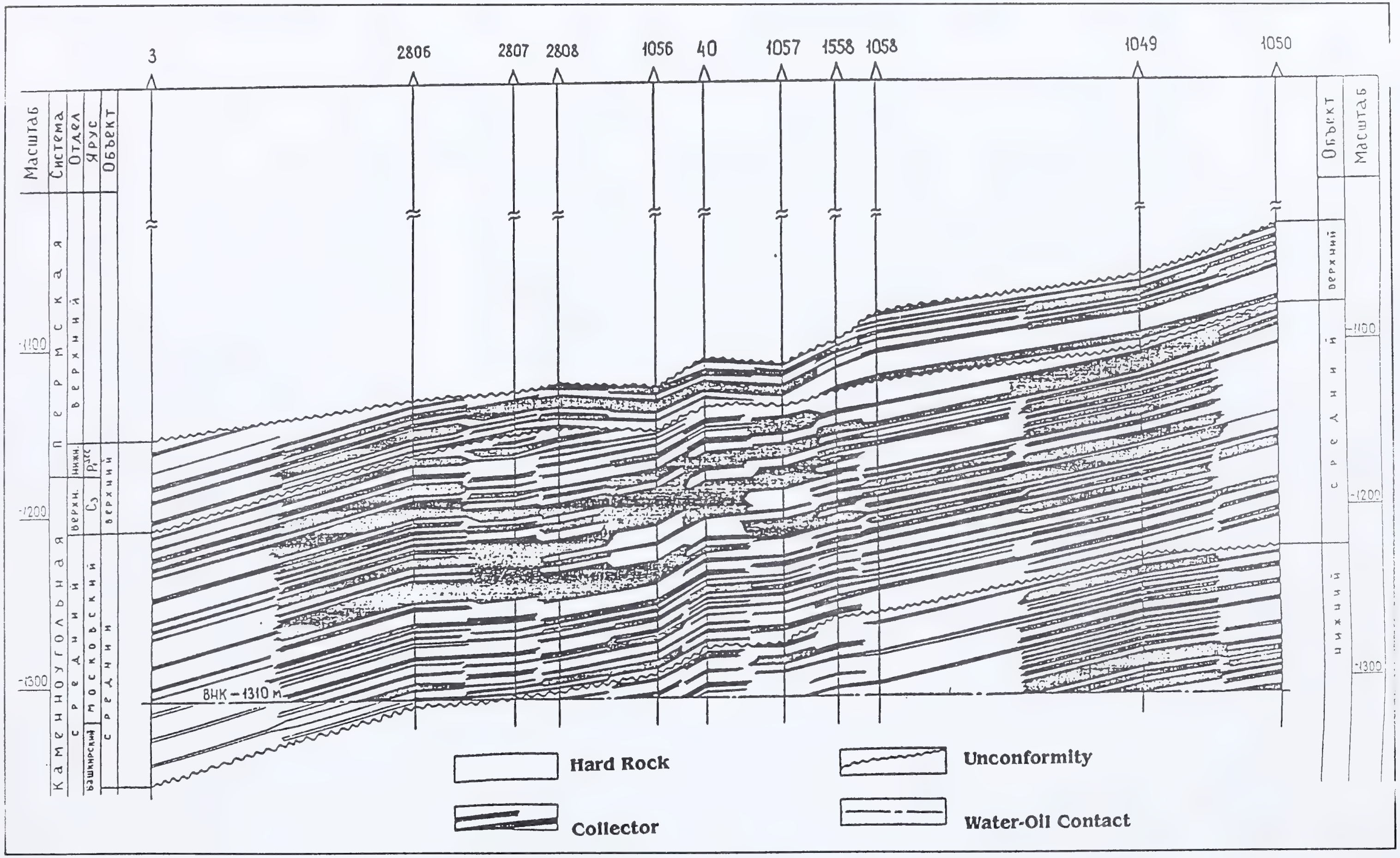
As far as deposits of viscous, semi-solid, and solid tars, which amount to 70 percent of total reserves, are concerned, their development is found to be possible using shaft or open-pit mining. The choice of these methods is dictated by the mode of occurrence of productive formations.

The Soviet Union possesses equipment required to use these methods, as well as one to extract bitumen from rock. Even now, under conditions in Tataria, both shaft and open-pit mining methods for bitumen production can be technically realized and economically proved in five deposits. So, actual surface (open-pit) mining of tar sands in the Sugushlinsk field (as well as all similar deposits) provides profitable recovery of essential amounts of bitumen during a long period of development. Moreover, near-total extraction of oil is achieved, whereas this method in its economic indicators approaches bore-hole mining.

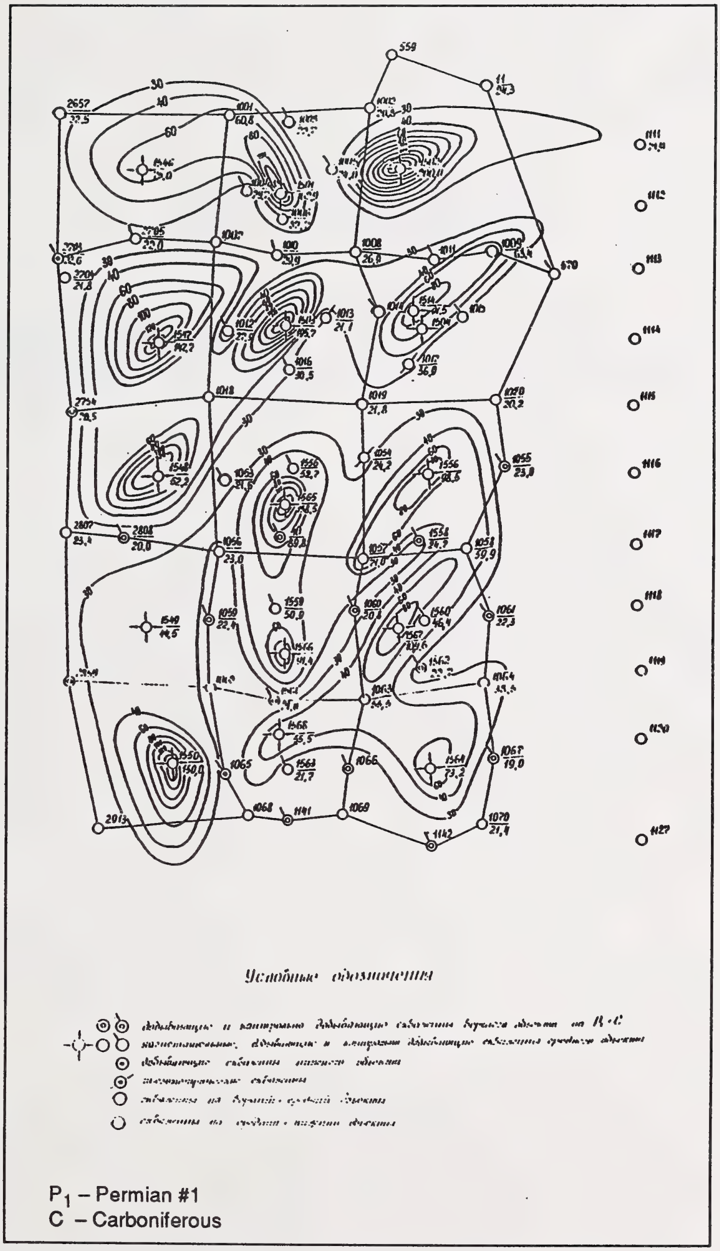
The prime cost of one ton of bitumen is about $41.40 (29 roubles). In the case of using tar sands from which the bitumen was extracted, as building material (for manufacturing of lime-and-sand bricks and expanded-clay lightweight concrete), it can be reduced to $23 (16 roubles).

The thermal mining method developed in the Soviet Union, which happily combines advantages of bore-hole and shaft mining, appears to possess the requirements essential for field application.

Certainly, in Tataria, the production-resource capabilities are not restricted to tar deposits in Permian sediments. One should also mention the long-term prospective for obtaining hydrocarbons from synthetic bitumen occurring in Devonian and Carbonic formations. According to available estimates, reserves of such tars in Volga-Urals region are about 300 billion tons of rock. This is a huge and real reserve of commercial hydrocarbon raw material. Good prospects are characteristic of some other regions. Thus, in Azerbaijan there have been discovered more than ten fields of tar sands that contain bitumen of high quality which can be developed by pit mining. Rather essential reserves of tar sands are available in the Olenekskiy field in Eastern Siberia as well as in some other regions of the country.



Usa deposit, steam injection site, geological profile



Isothermal contours of steam injection site on Usa deposit (P. + C)

APPENDIX 2

Okha (Sakhalin Island)

1. Paper, "Application of Heat Carriers Upon Development of High Viscous Heavy Oil Fields in the U.S.S.R."

APPLICATION OF HEAT CARRIERS TO DEVELOPMENT OF HIGH-VISCOUS HEAVY OIL FIELDS IN THE U.S.S.R.

A.A. Bokserman, All-Union Oil and Gas Scientific Research Institute, A.G. Tarasov, VNII, D.G. Antoniadi, RPA, K.E. Dzhalolov, RPA and V.A. Lavrennikov, Sakhalin-NIPI-neftegaz

(PAPER NO. 214)

ABSTRACT

Basic principles of oil field development in the U.S.S.R. using thermal techniques are described.

The Okha oil field operation results confirmed the feasibility of steam stimulation followed by waterflooding for a terrigenous reservoir.

Mathematical models applicability is shown to forecast the thermal technique implementation.

Significant energy consumption for oil production in the process of change to a waterflood followed by thermal slug was confirmed in other projects taken as an example, where development was completed by thermal stimulation.

A considerable reservoir temperature increase is necessary for carbonate reservoirs, where the main factor of oil recovery improvement is a capillary soaking in comparison to terrigenous reservoirs. Rise in efficiency rise may be achieved by cyclic thermal stimulation.

Use of a cyclic thermal waterflood in the Usa oil field allowed production of more than 200 thousand tonnes of incremental oil in comparison to continued heat carrier injection.

INTRODUCTION

Heat carrier injection (steam and hot water) for enhanced oil recovery (EOR) during development of heavy oil fields is widely used for thermal stimulation in the U.S.S.R.

Field tests and commercial application of this method are implemented in 17 oil fields. The injected steam volume increased 50 mllion (mln) tonnes and cumulative oil production increased 15 mln tonnes from the start of the method application.

The basic principles of thermal techniques in the U.S.S.R. for EOR are as follows (Ivanov *et al.*, 1986):

- Reservoir thermal stimulation is carried out together with waterflooding by creating and driving thermal slugs in the reservoir.
- Well patterns should be in rows or less intensive areal ones for better control of the development process.
- Creation of linear thermal fronts and their movement through the reservoir.
- Transfer of working agents for more rational heat utilization and thermal slug size correction.
- Optimization of well spacing density, injection and fluid production techniques, thermal slug sizes for ultimate utilization of thermal and hydrodynamic interference of layers with different permeability.
- Carrying out cyclic reservoir stimulation for intensive oil recovery from reservoirs of low permeability.
- Carrying out selective thermal treatment of producing wells bottom-hole zones to regulate heated zone migration and oil displacement.

USE OF THERMAL SLUGS UNDER THE CONDITIONS OF THE OKHA OIL FIELD TERRIGENOUS RESERVOIRS

Injection of steam followed by cold water as a recovery technique was completely tested and successfully used in a commercial project of the Okha oil field (Bokserman *et al.*, 1979).

The Okha oil field is located on the Sakhalin Island and is a multilayer reservoir. Depth of the multilayer formation containing highly viscous oils ranges from 30 to 700 m (Figure 1). The reservoir consists of friable sands of 0.3–1.5 mkm^2 permeability. Oil viscosity in various reservoirs differs from 100 to 3000 mPa•s and increases upwards.

The oil field has been under development since 1922 using solution gas drive at first and then gravity drainage with poor edge water drive. In the 1950s injection of water and air was carried out to intensify the development, but due to the high viscosity of the oil

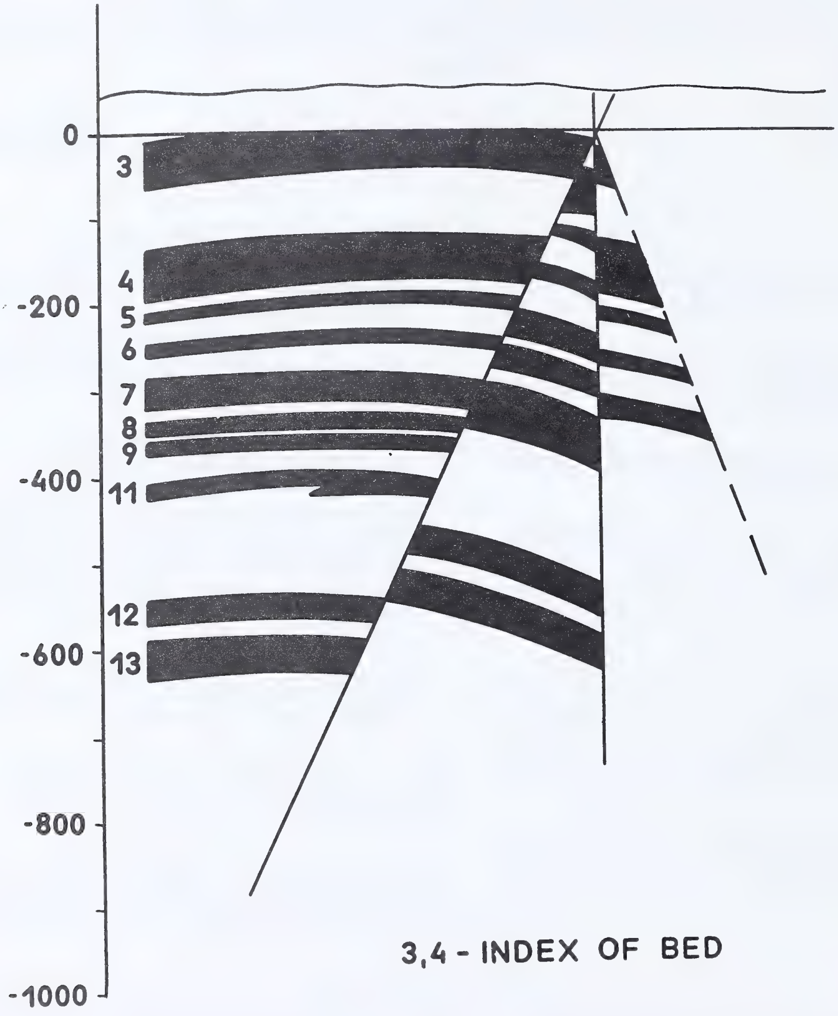


Figure 1. *Geological cross-section of the Okha oil field*

quick breakthrough of working agent into the wells occurred and positive results were not achieved. In the middle of the 1960s oil recovery in the oil field reached only 14–19% in spite of a very dense well pattern.

Steam injection in the reservoir was initiated in 1968 in the oil pool of the 4th pay unit, Xth block in 5 injection wells and then increased continuously.

The volume of the injected steam in the oil pool reached a maximum in 1973, then decreased continuously to 148 thousand tonnes in 1977. The injected steam volume decline was accompanied by an increasing volume of injected water. In 1979 a change to pushing the created thermal slug by cold water was initiated. Further steam injection was carried out into poorly heated sections of the oil pool, increasing the sweep efficiency by thermal stimulation. The total amount of the injected agents at present is about 18 million tonnes or 2.5 HPV. Oil production increased rapidly from the beginning of stimulation and reached its maximum in 1972-1973. In subsequent years oil production decreased with an increase of total liquid production. This indicates that the oil pool is in a stage when the thermal slug is being pushed by cold water. The natural drop in production in the process of oil pool depletion is associated with a decline of power consumption for oil recovery due to modified technology application. In the period 1973-1986, specific steam consumption per 1 tonne of produced oil dropped from 2.79 to 1.64 tonnes. The history of oil production in the pool is shown in Figure 2. Application of steam injection allows annual oil production to increase more than 4 times and exceeds the maximum level achieved in depletion drive.

The incremental produced oil volume due to thermal stimulation increased 2.7 times in the oil pool.

COMPARISON OF CALCULATED AND ACTUAL PARAMETERS OF OIL FIELD DEVELOPMENT

At present the development of the 4th pay unit, Xth block is in a final stage, therefore it is of a great scientific and practical importance to estimate the applicability of mathematical simulation used in forecasting a steam stimulation technique followed by a waterflooding.

Using the actual field development history of the 4th pay unit, Xth block by thermal stimulation a target conversion of a mathematical model was done. An actual and calculated oil recovery as a function of the volume of injected agents for a typical pattern of the development system is shown in Figure 3.

Satisfactory matching of calculated and actual values allowed use of a mathematical model for transferring the development history for the whole 4th pay unit, Xth block. Actual procedure of putting separate patterns into production and volumes of injected steam and water into each well were taken as input information. Output information was in the form of total oil and liquid production.

A comparison of certain actual and calculated values for steam injection, oil production and recovery in the form of annual and total indices is given in Figure 4 and 5. The comparison of the dynamics for actual and calculated indices of the 4th pay unit, Xth block development shows the ability of the accepted mathematical model to describe correctly very complicated thermal and hydrodynamical processes of a thermal slug creation and its movement in the reservoir as well as oil displacement towards the wells. The accepted mathematical model was used for designing some oil fields with terrigenous reservoirs in the U.S.S.R.

ENERGY EFFICIENCY OF THERMAL SLUGS CONCERNING THE OIL FIELD RESULTS

The advantage of a steam injection followed by waterflooding lies mainly in the decrease of either a heat input or a specific steam consumption for oil production.

Figure 6 shows the dependence of the specific steam consumption per 1 tonne of produced oil for typical oil fields which are developed by steam injection followed by waterflooding and are in the final stage of the development (Vakhitov *et al.*, 1983). This refers mostly to the above mentioned 4th pay unit, Xth block of the Okha oil field and the Khorasany oil field with almost similar characteristics. The Borislav oil field has lower oil viscosity (4 mPa•s) and had a high degree of reserves depletion before the application of thermal stimulation technique, *i.e.*, low residual oil saturation. Curves presented in Figure 6 illustrate a substantial decrease of thermal energy consumption after a change to water injection.

For the Khorasany and Borislav oil fields the initial stage of a thermal stimulation was characterized by high energy consumption. For the Borislav oil field this consumption is higher than the thermal energy quantity in the produced oil. Implementation of a thermal slug process allowed reduction of energy consumption as well as economic expenditures to normal levels.

INJECTION OF HEAT CARRIERS FOR DEVELOPMENT OF CARBONATE RESERVOIRS

A significant quantity of world reserves of high viscous oils is in carbonate reservoirs. The Usa oil field, located in the northern part of the USSR, may serve as an example.

The Permo-Carboniferous oil pool of this oil field has a depth of more than 1000 m and represents a carbonate porous-cavernous — fractured reservoir about 300 m thick, with oil viscosity is near 700 mPa•s.

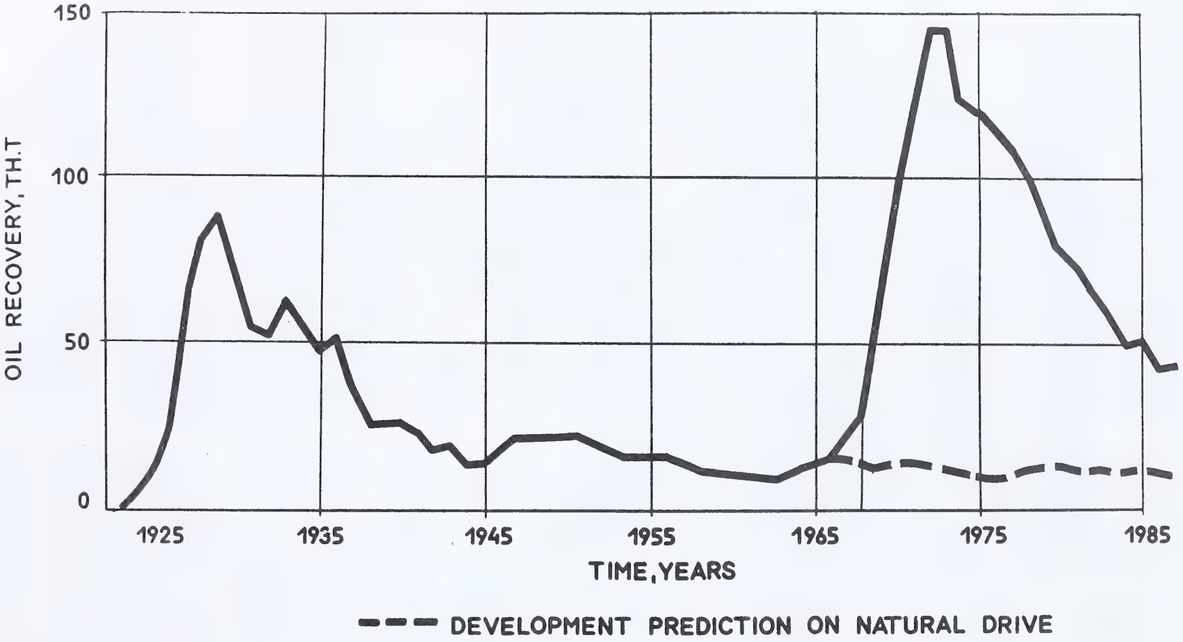


Figure 2. *Oil production in the 4th pool, Xth block of the Okha oil field*

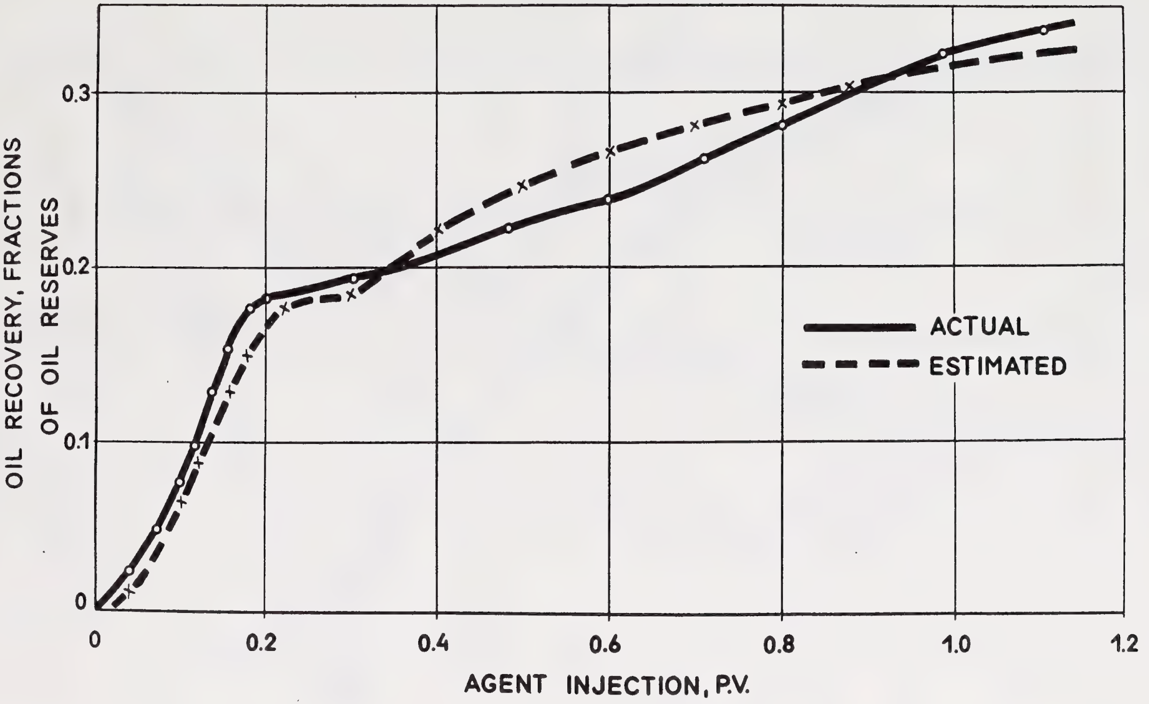


Figure 3. *Actual and calculated oil recovery for a development* pattern in *the Okha Oilfield*

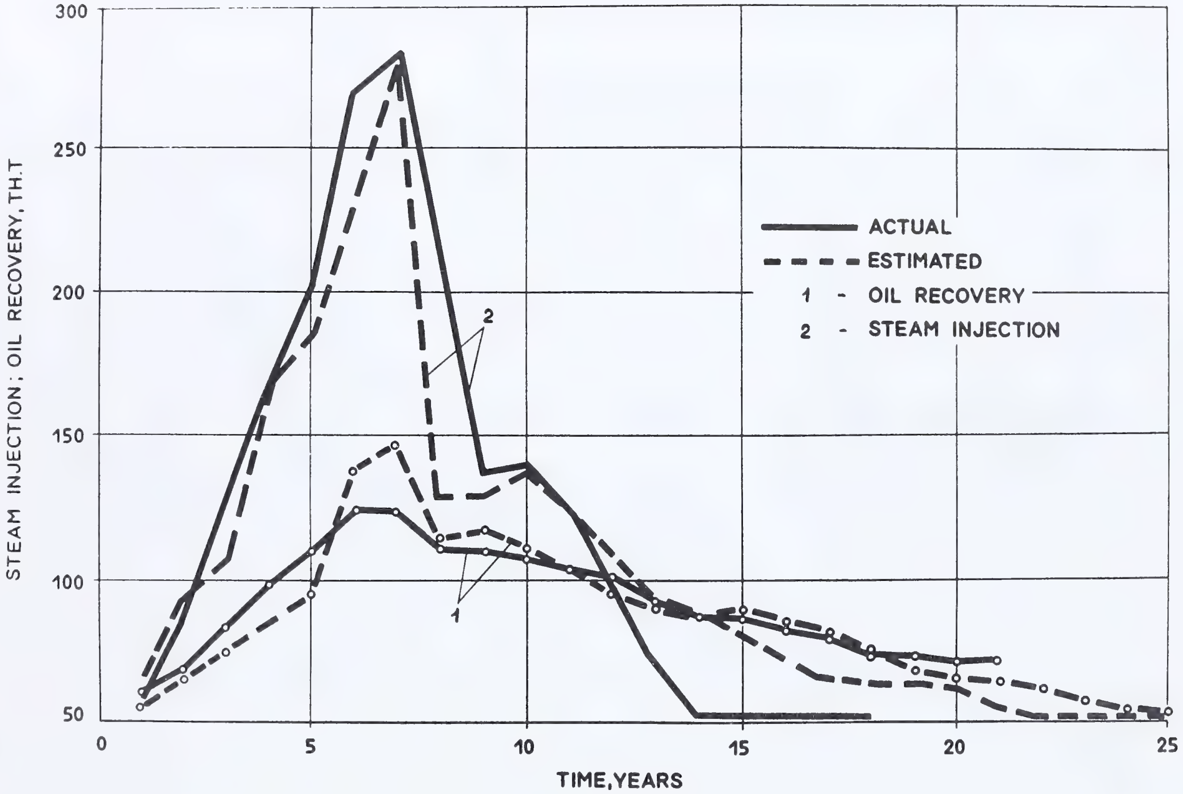


Figure 4. *Comparison of actual and calculated annual development indices of the 4th pool, Xth block, Okha Oil field*

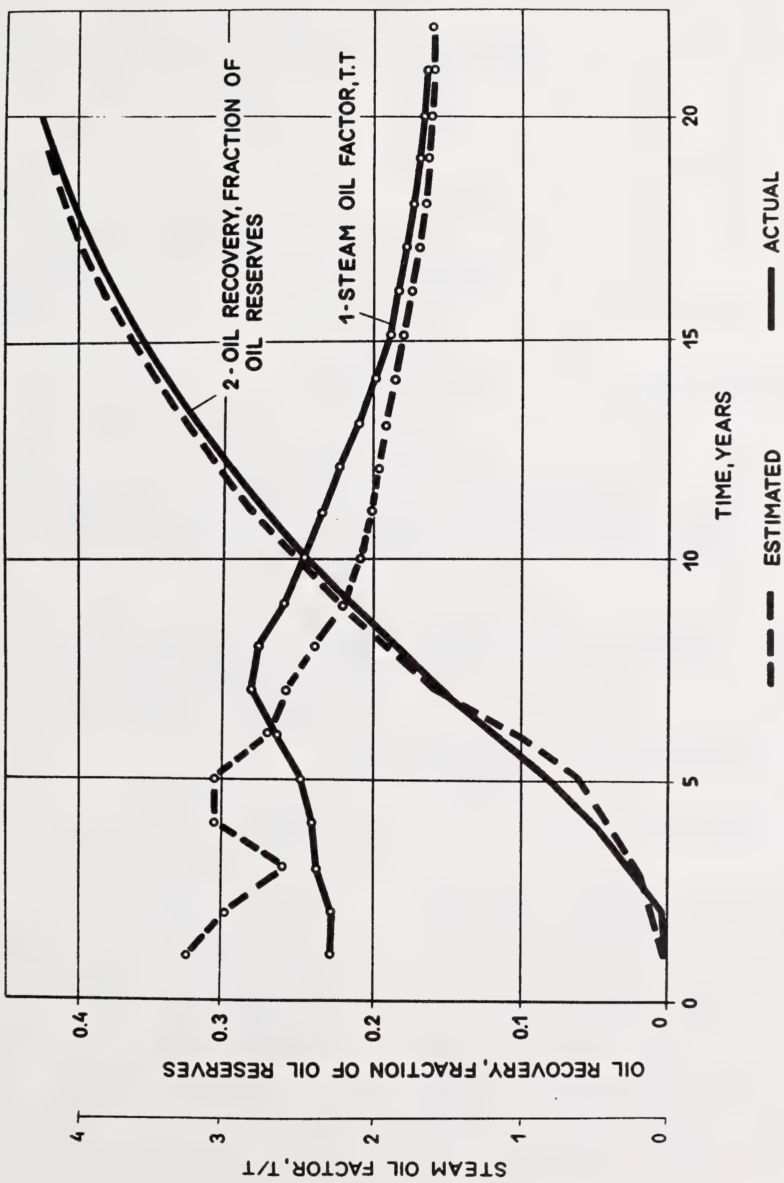


Figure 5. *Total values for oil production and specific steam consumption in development of the 4th pool, Xth block, Okha Oilfield*

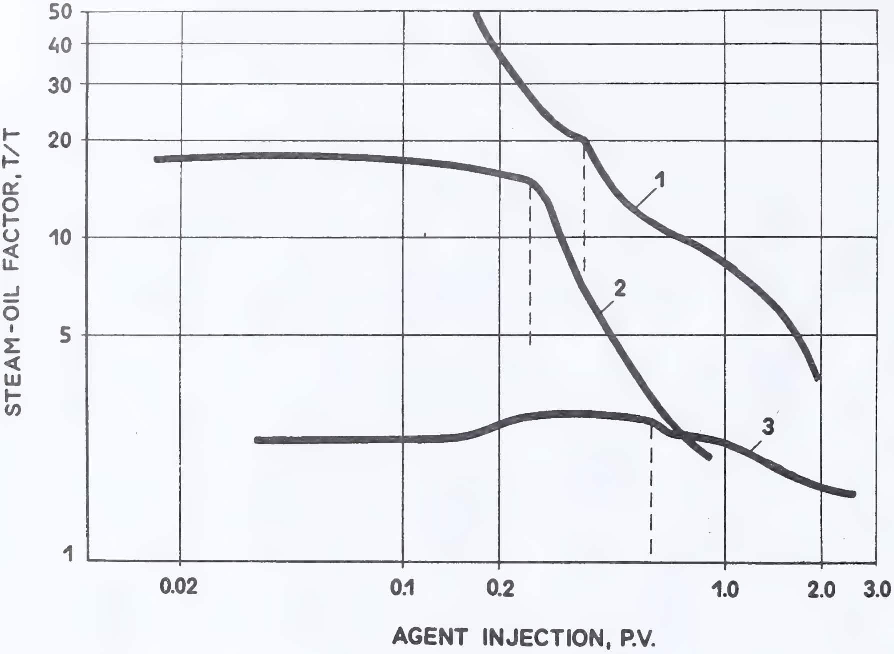


Figure 6. *Specific steam consumption versus working agent injection for oil production; 1. the Borislav oil field; 2. the Khorasany oil field; 3. the Okha oil field (4th pool, Xth block); vertical dashed line, water injection*

The oil pool was put in production in 1977 on depletion drive with estimated oil recovery of 10% confirmed by actual field data.

According to the efficiency of the thermal techniques application to this oil field takes priority as a candidate for steam stimulation of the reservoir. Depth of the reservoir and its characteristics are factors complicating a large scale implementation of this process.

In early 1980s the USSR had neither experience nor bore hole equipment for thermal stimulation at large depths. Experimental studies carried out on cores taken from the Usa oil field revealed that an effective capillary imbibition takes place at a temperature increase of more than 180–200°C. Figure 7 shows a quantitative comparison of oil recovery *versus* temperature both for terrigenous and carbonate reservoirs. These data indicate the necessity to increase the carbonate reservoir temperature to higher values compared to the clastic reservoir to provide for similar oil recovery values (Tarasov and Kzhalalov, 1986).

Thus, for an effective oil production from the carbonate reservoirs it is necessary either to stimulate a larger part of the reservoir by a high temperature agent or use some other factors as oil recovery mechanisms promoting their action at lower temperatures.

Energy of oil-dissolved gas is one of the factors. Reservoir temperature rise leads to an oil saturation pressure increase and to intensification of low-viscous oil displacement from blocks to fractures. Cyclic change of reservoir pressure will give an additional effect.

The Usa oil field conditions correspond completely to theoretical knowledge of a reservoir stimulation technology. In 1982 water injection was initiated to create filtration in the reservoir. The temperature of water was 250–270°C and in the injection rates was constant (Dodonova and Samartzeva, 1985). Figure 8 shows a pilot area which consists of 15 injection wells and 57 producing and control wells. In five months, oil production per day increased 1.5 times but in 1987 development indices somewhat decreased, mainly due to a considerable increase of water cut. During this period oil displacement from fractures and highly permeable zones by condensate took place. Condensate temperature was close to that of the reservoir. In late 1983 and in 1984 the reservoir responded positively to thermal stimulation and the oil rates increased in the area. For the first three years (1982–1984) application efficiency of thermal techniques under conditions of the Permo-Carboniferous oil pool of the Usa oil field was proved. Cumulative oil production reached more than 900 thousand tonnes, 50% due to thermal techniques.

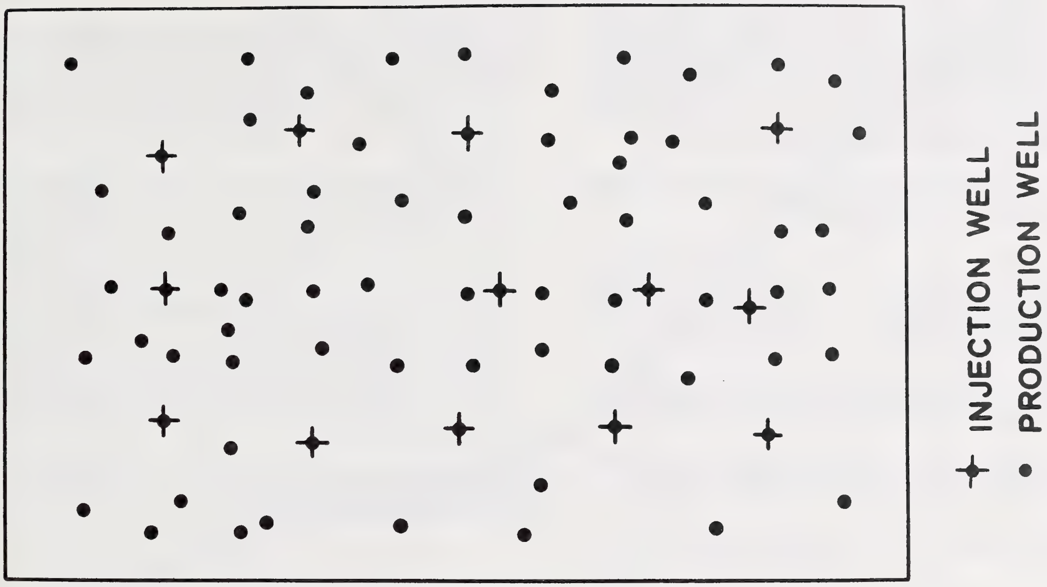


Figure 8. *Pilot prospect area, Usa oil field*

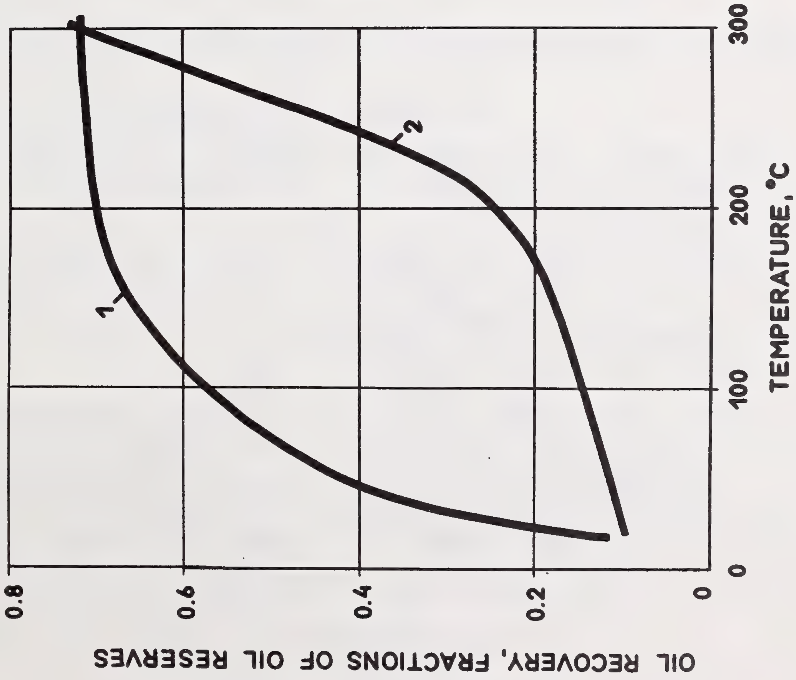


Figure 7. *Oil recovery factor versus temperature; 1. clastic reservoirs; 2. carbonate reservoirs, Usa Field*

At the same time, based on field results analysis, an active advance movement of a heat carrier along fracture-cavernous channels and its break to producing wells was noted. It resulted in a high level of a water-cut of the wells, in some cases up to 80%. For three years water-cut in the area increased from to two to 55%. Response to the heat carrier injection in the wells located beyond the area boundaries was revealed. In particular, those wells located some 1.5–2.5 km from the injected zone, appeared to be under drive created in the reservoir.

Figure 9 shows the oil production in the pilot area from the beginning of its development.

In 1985 a pilot test of a reservoir cyclic thermal technique was initiated. Experience of a working agent cyclic injection in conventional waterflooding was used in creation of this technique.

In 1986 the technology was implemented in four patterns, in 1987 in 10 and in 1988 in all 15 patterns of the area.

EVALUATION OF A TECHNOLOGICAL EFFECT IN A CYCLIC THERMAL WATERFLOODING

The basic prinçiple of a technological effect from cyclic thermal stimulation lies in the scientific justification of an oil production increase or a favorable change in other indices defining the new technology feasibility.

The key elements are as follows:

- A process of a continuous heat carrier injection is a basis for a technological efficiency determination.
- Basic technology is determined by indices obtained in matching a mathematical model to the field development history during continuous heat carrier injection.
- A decomposition principle is used to determine development factors of the basic technology, *i.e,.* division of a complex multi-well development system into separate patterns or sections, characterized by a definite geology, reservoir engineering parameters and sequence of putting the patterns into production.
- In matching a mathematical model, a balance between production and heat carrier injection is taken into consideration by means of applying corrections for design indices.

The basic results of application such a technique for the Usa oil field are given in Figure 10.

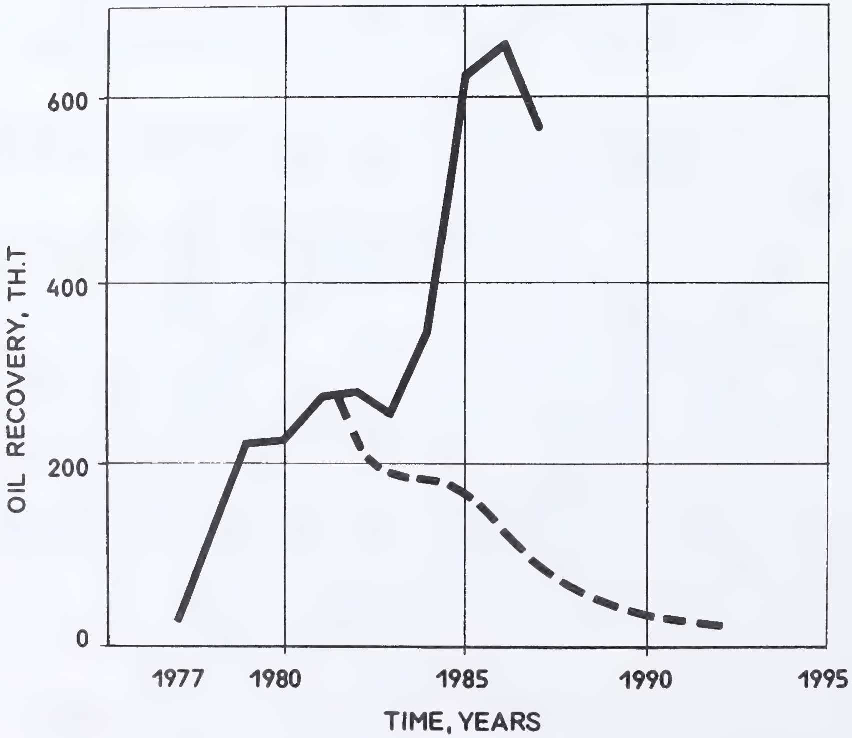


Figure 9. *Oil production in the pilot area*

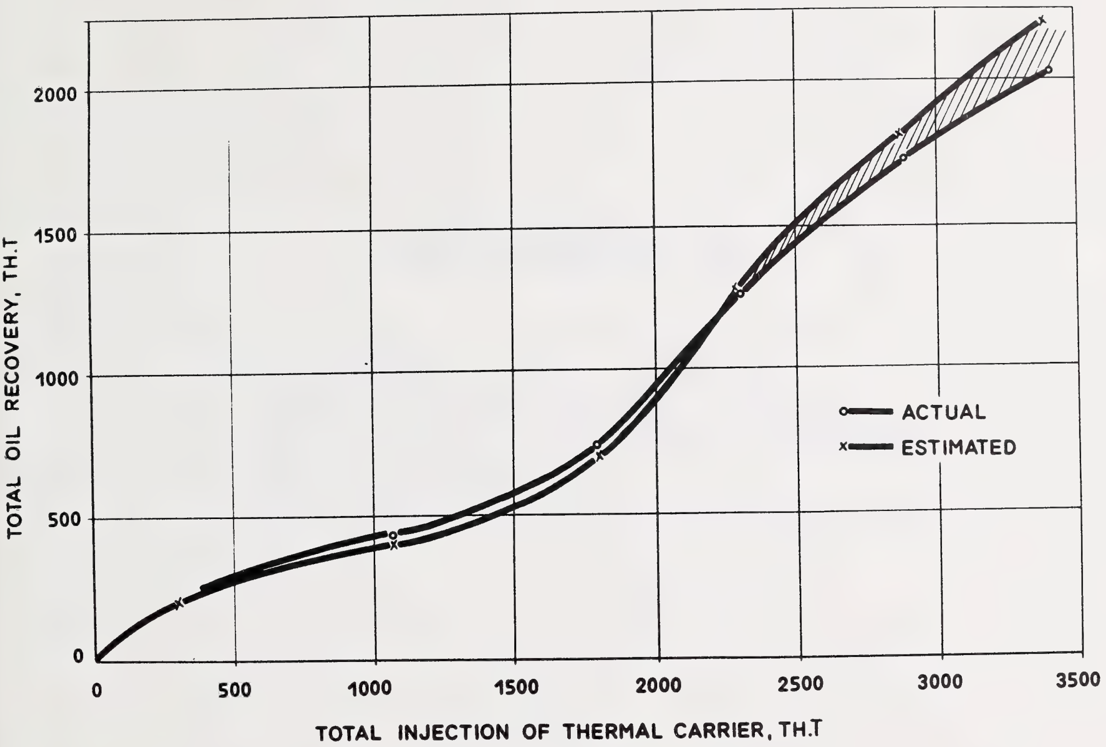


Figure 10. *Technological efficiency in the process of cyclic thermal flooding in the pilot area of the Usa oil field*

Cumulative oil production due to this technique compared to continuous heat carrier injection equals 203 thousand tonnes per nine thermal stimulation patterns, including 107 thousand tonnes or 25% of total oil production in 1987.

Implementation of the reservoir cyclic thermal stimulation stabilized water cut and reduced heat carrier consumption for oil production.

CONCLUSIONS

- Use of a steam injection followed by waterflooding in terrigenous reservoirs reduces thermal agent consumption for oil production considerably.
- Cyclic thermal stimulation technique in carbonate reservoirs increases oil rates and decreases energy consumption per 1 tonne of produced oil with the similar quantity of heat introduced in the reservoir.
- Mathematical models applicable for an engineering forecast under conditions of heat carrier injection in oil field development are proved.

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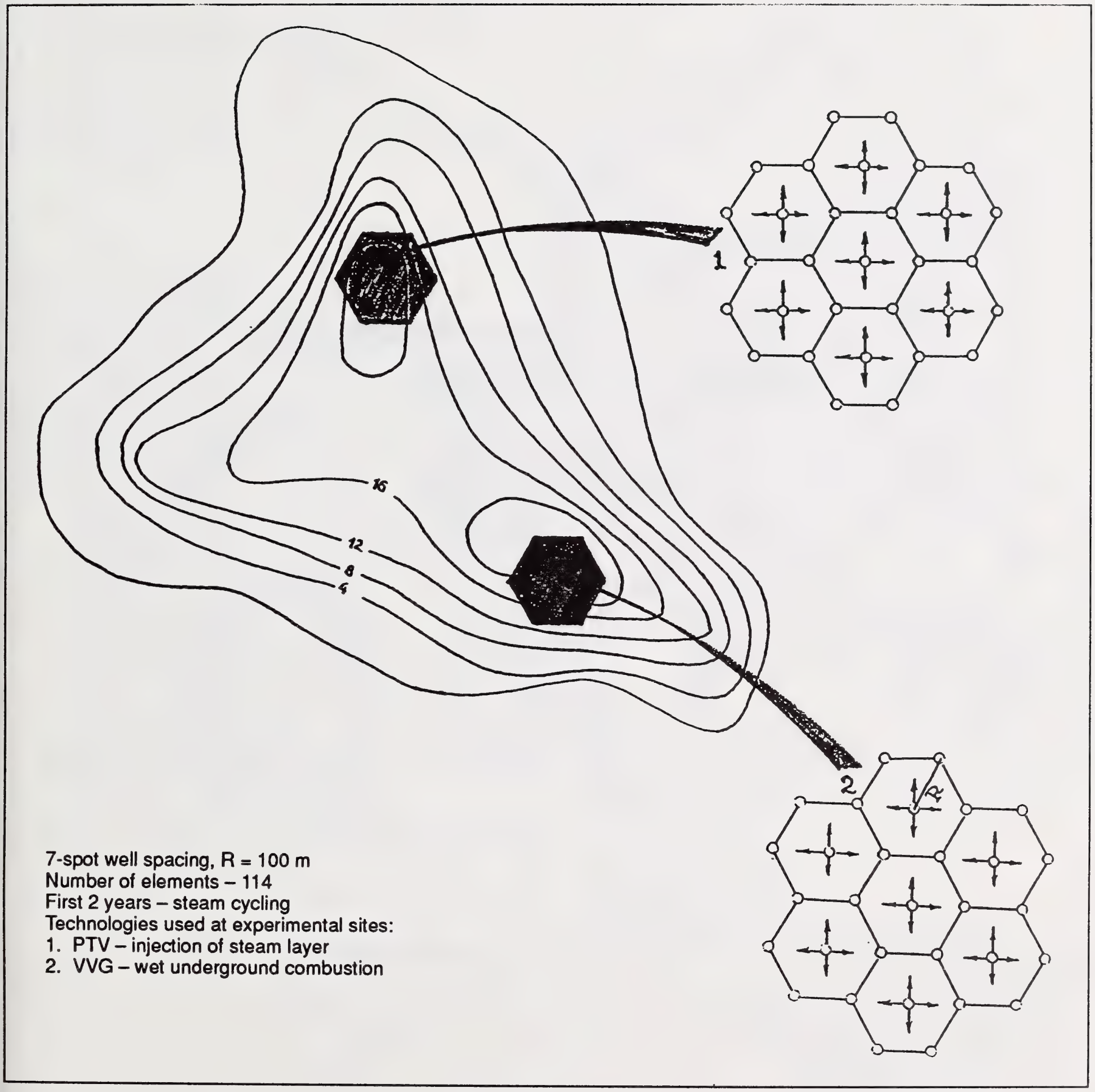
APPENDIX 3

Tataria - Bugulma

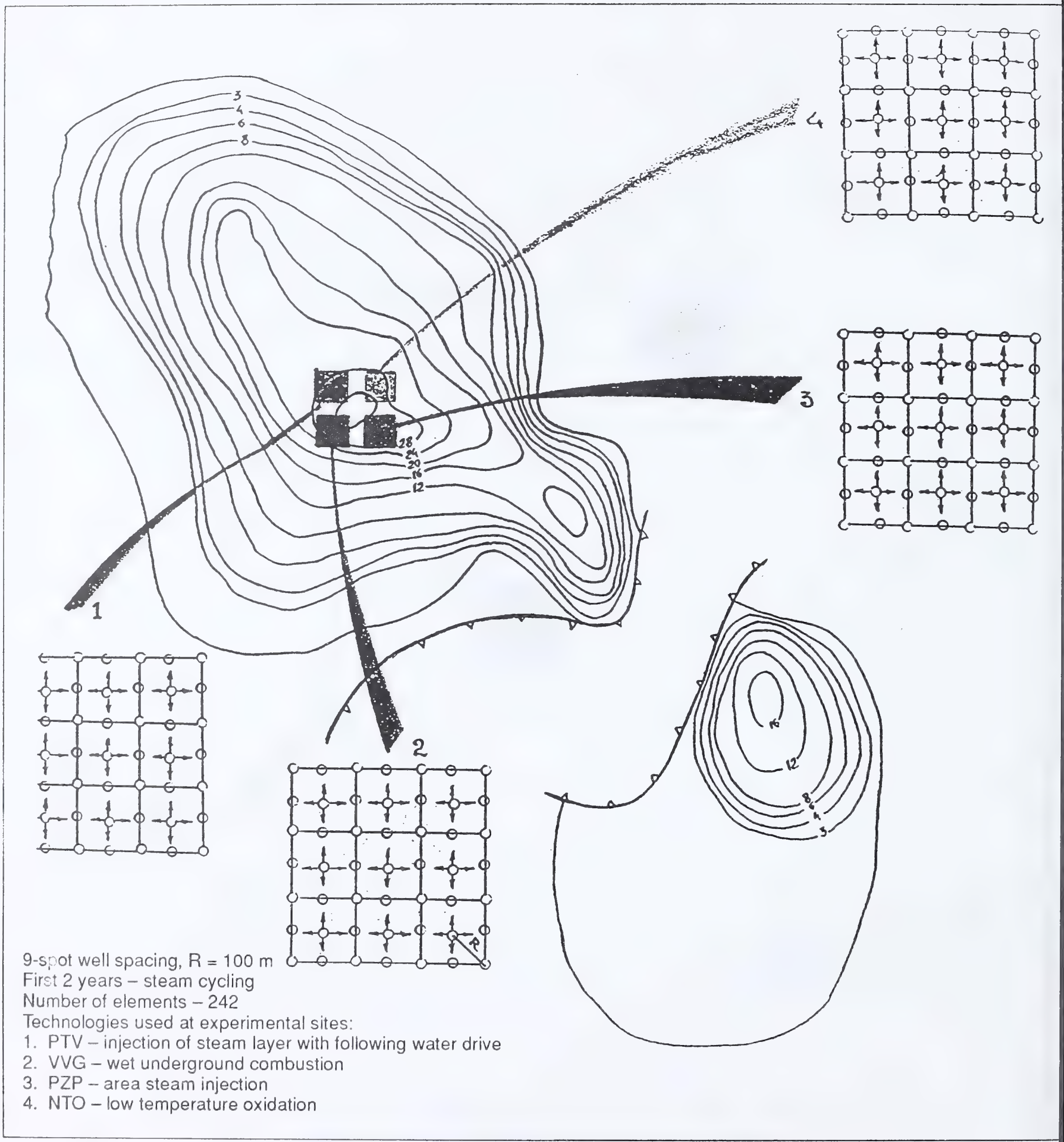
1. Diagrams of pilot projects (supplied by VNIIneft).
2. Method of thermoacoustic conditioning of the near-well zone.
3. Unit ANC-1 for heating of wells.
4. Heating of bitumen pay zone by current of industrial frequency.



7-spot well spacing, R = 100 m
Number of elements – 114
First 2 years – steam cycling
Technologies used at experimental sites:

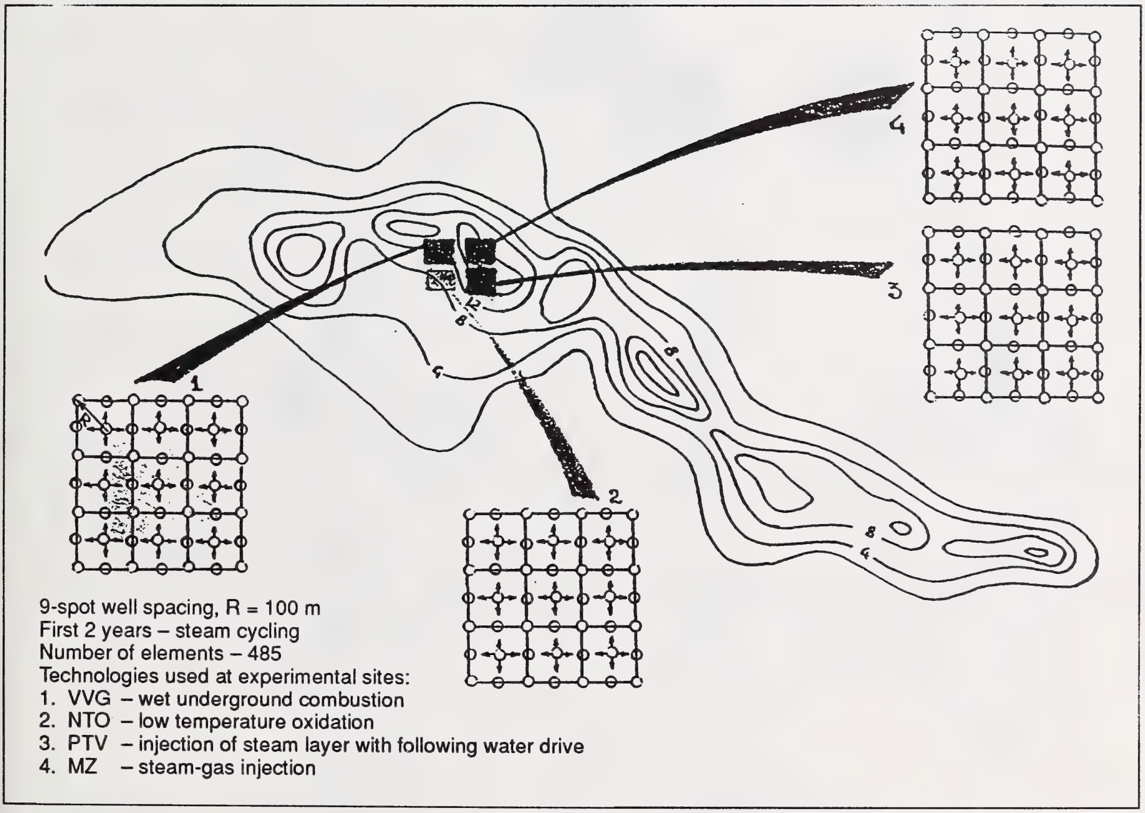
1. PTV – injection of steam layer
2. VVG – wet underground combustion

Mordovo-Karmalskoe deposit of natural bitumen



9-spot well spacing, R = 100 m
First 2 years – steam cycling
Number of elements – 242
Technologies used at experimental sites:
1. PTV – injection of steam layer with following water drive
2. VVG – wet underground combustion
3. PZP – area steam injection
4. NTO – low temperature oxidation

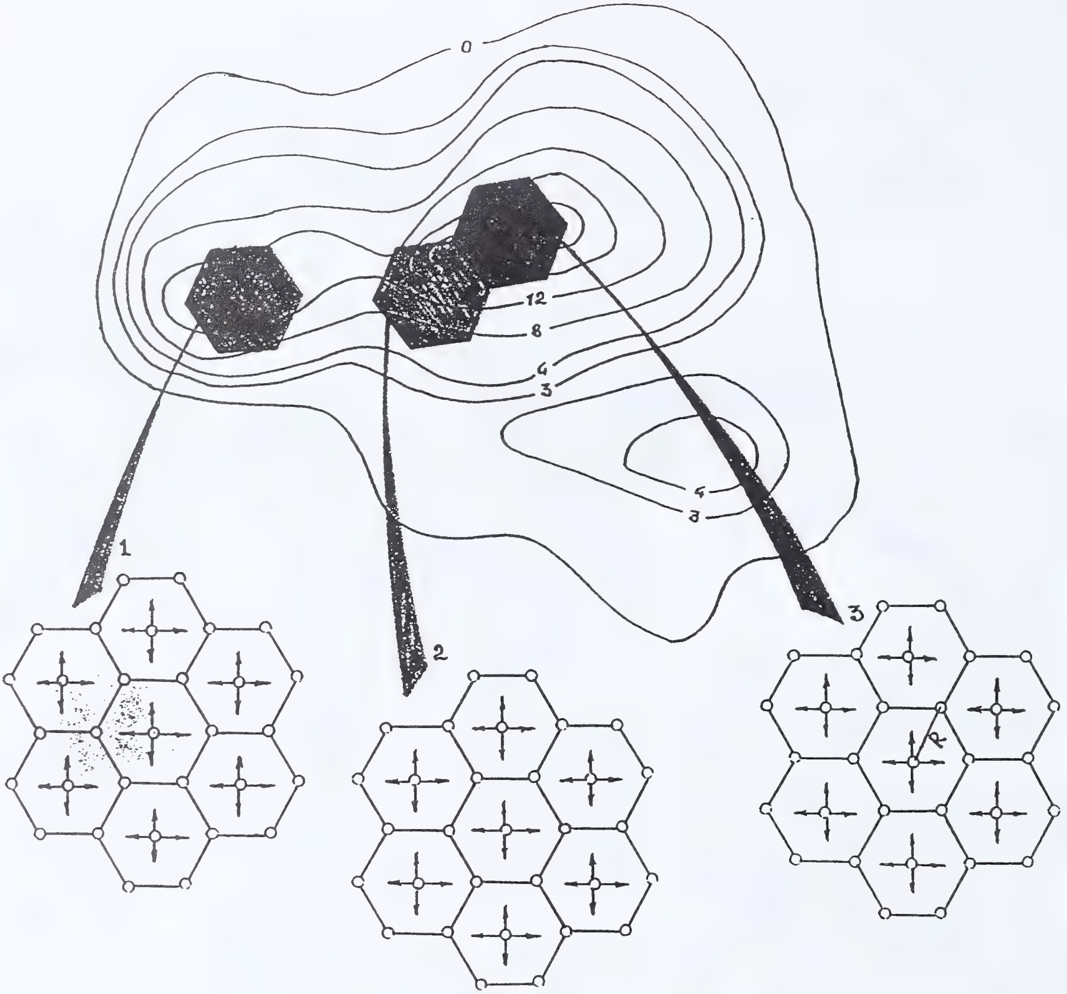
Ashaltsinskoe deposit of natural bitumen



9-spot well spacing, R = 100 m
First 2 years – steam cycling
Number of elements – 485
Technologies used at experimental sites:

1. VVG – wet underground combustion
2. NTO – low temperature oxidation
3. PTV – injection of steam layer with following water drive
4. MZ – steam-gas injection

Nizhne-Karmalskoe deposit of natural bitumen



7-spot well spacing, R = 100 m
First 2 years – steam cycling
Number of elements – 84
Technologies used at experimental sites:

1. VVG – wet underground combustion
2. PTV – injection of steam layer with following water drive
3. PZP – area steam injection

Podlesnoe deposit of natural bitumen

Method of thermoacoustic conditioning of near-well zone

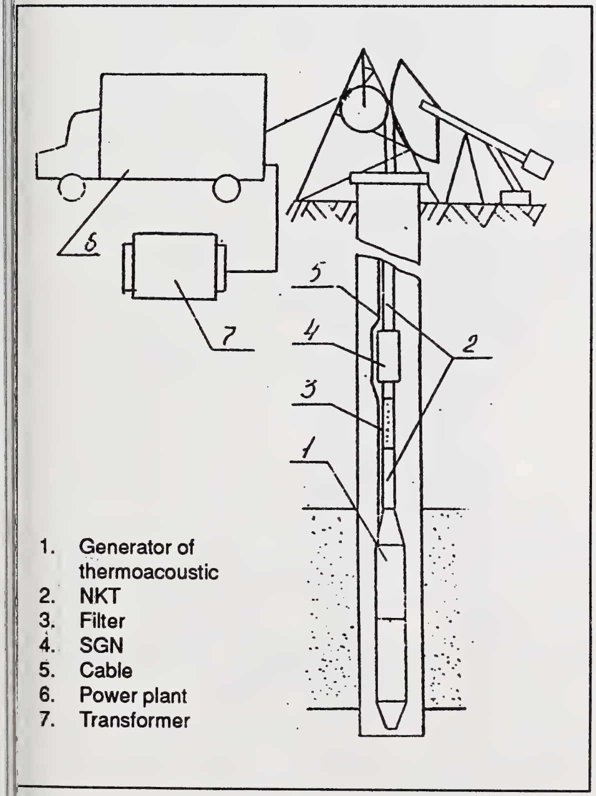
Method designed for clearing near-well zone from clay, mechanical, particles, mud, paraphine, tar, asphaltine, hydrite of gases. Method is used for the following conditions:

Daily oil production	>1/2 t/day	Pay zone	>2m
Depth	1500–2000 m	Temperature	<65°C
Casting diameter	>130 mm	Porosity	>5%

Two types of generators are used:

1. 63 kW, 14–22 kHz
2. 15 kW, 16.57 kHz

Designed by: 423200 Bululma
BKO 'Natural Bitumen'
Kalinina str. 71
USSR



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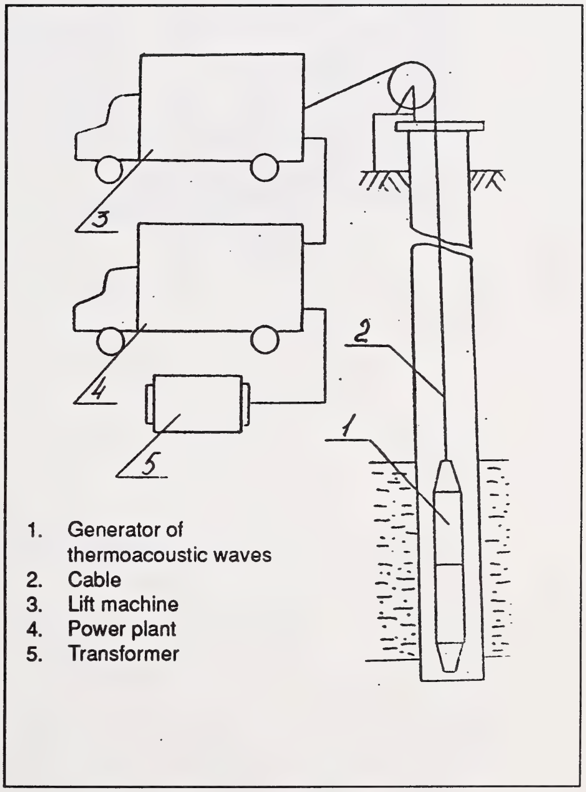

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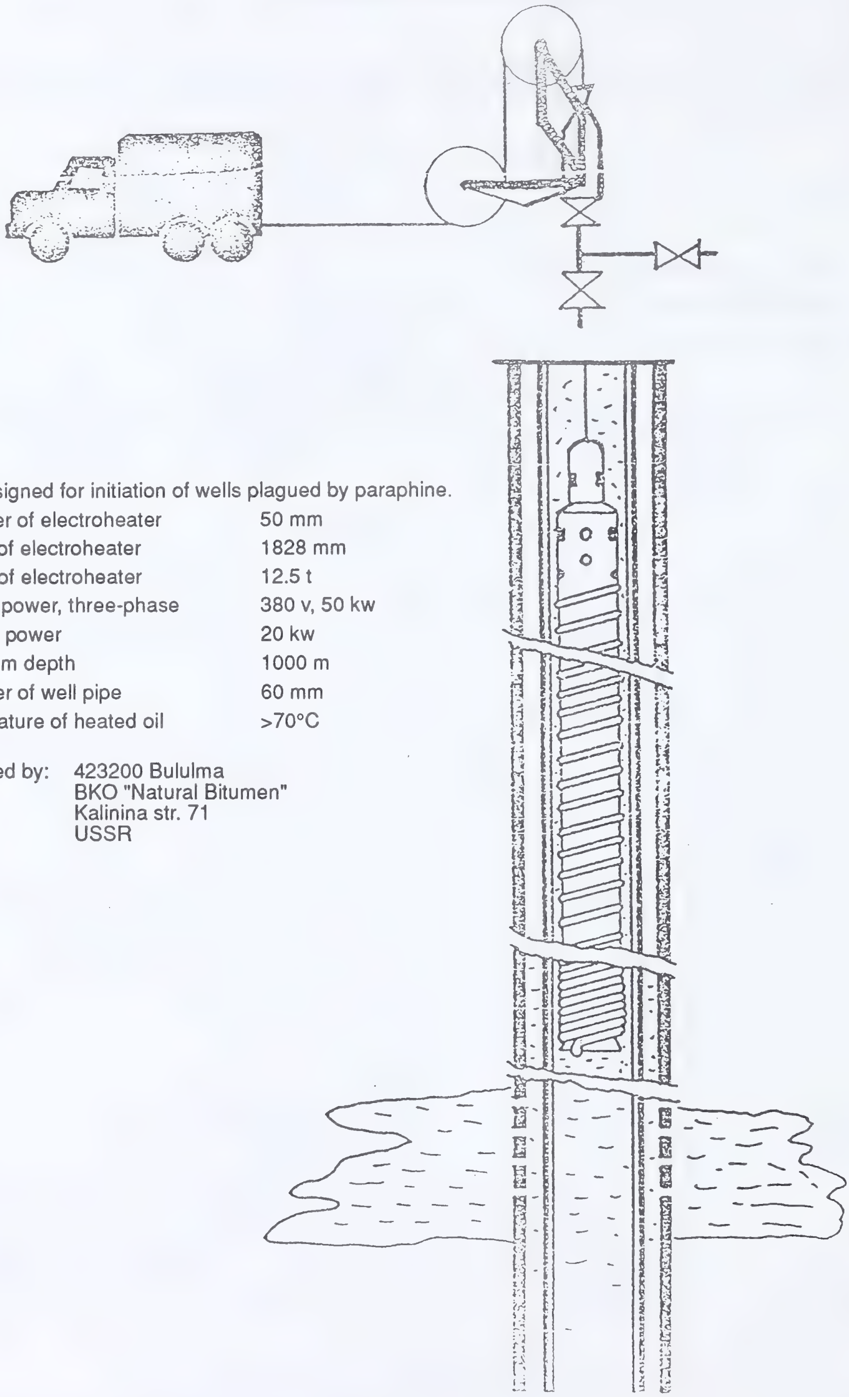
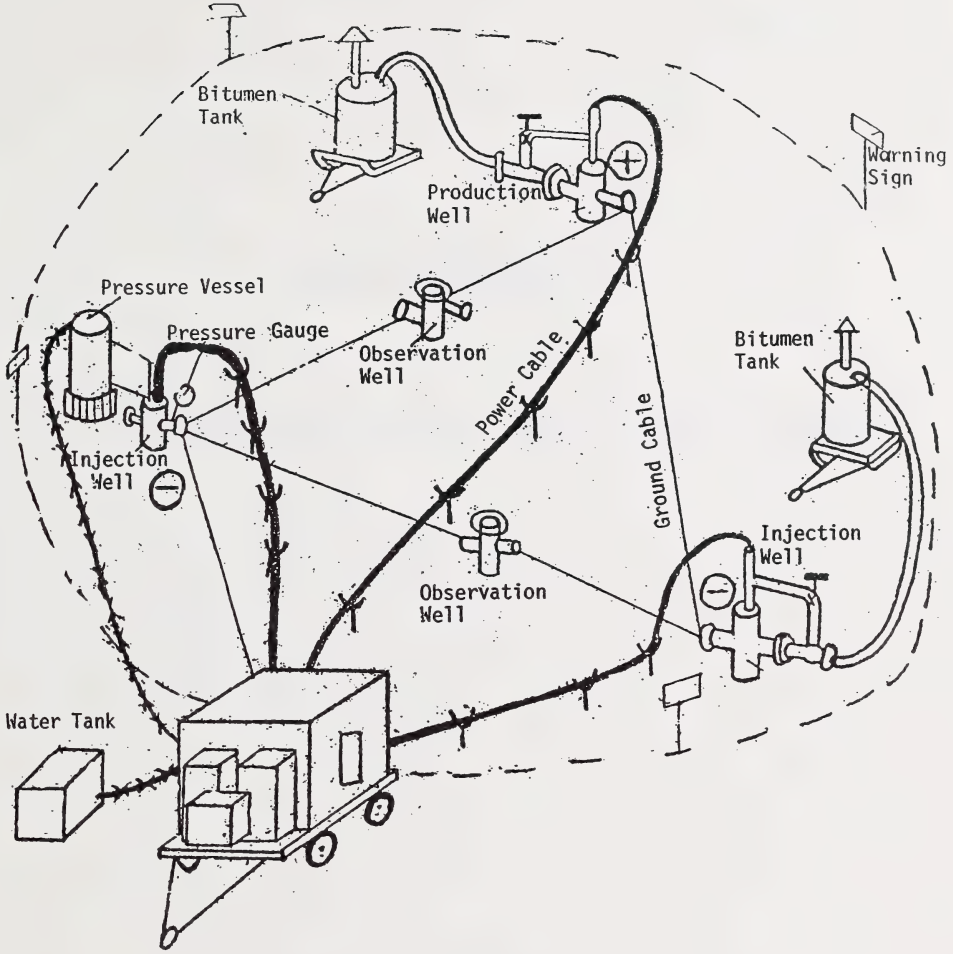


Unit designed for initiation of wells plagued by paraphine.

Diameter of electroheater	50 mm
Length of electroheater	1828 mm
Weight of electroheater	12.5 t
Electric power, three-phase	380 v, 50 kw
Heating power	20 kw
Maximum depth	1000 m
Diameter of well pipe	60 mm
Temperature of heated oil	>70°C

Designed by:
423200 Bululma
BKO "Natural Bitumen"
Kalinina str. 71
USSR

Unit ANC-I for heating of wells



Method is designed to heat bitumen pay zone to the water boiling temperature.
Specific energy rate – 120 kw/(hr m)
Time span of heating at 50 m spacing – 0.5 year

Designed by:
423200 Bululma
BKO "Natural Bitumen"
Kalinina str. 71
USSR

Heating of bitumen pay zone by current of industrial frequency

APPENDIX 4

KIEV

1. Letter to AOSTRA from Mr. L. Fillimonov, Minister of Oil Industry.

1,900 US

СССР
МИНИСТЕРСТВО НЕФТЯНОЙ ПРОМЫШЛЕННОСТИ

Москва, 113816
наб. Мориса Тореза, 26/1
тел. 231-23-63

URSS
MINISTÈRE DE L'INDUSTRIE PETROLIÈRE

26/1, Quai Maurice Thorez,
Moscou, 113816
tel. 231.23.63

20/425

„27" октября 1989 г.

500 Highfield Place, 10010-106
Street Edmanton Alberta,Canada
T513L8 403\427-7623, Aostra

Dear Mr Redford.

The USSR has a wide network of different pipelines for transportation of gas, oil, chemical and petrochemical products. Many of the products are toxic, fire hazardous and explosive and are causing problems connected with reliability and safety during transportation.

A Soviet delegation of experts from the E.O.Paton Electric Welding Institute, Gas and Oil ministry of the USSR, Scientific and Technological Complex "Nefteotdacha" ("Oil Recovery")is planning to visit Canada and the USA in January next year. The goal of this visit is to evaluate the state-of-the-art in regard to the mentioned problems including design regulations and standarts, all procedure inspections, tecnological processes and technical means of putting pipelines into operation, methods and technical means for pipelines diagnosis, computerized transportation control systems, etc.

During our talks with Mr.James Yurko and Vladimir Reitman who visited USSR on the invitation of "Nefteotdacha" we were informed that your company could assist our delegation. In this connection we kindly ask you to sponsor this trip, which can result in concluding contracts for purchasing in Canada the corresponding eguipment and technologies as well as elaboration of the joint works in the field of reliability and safety ensurance of transmissional pipelines.

Please, inform us of the possibility to render your assistance in the above mentioned matter on two adresses:

1. Mr. L.Filimonov
   Minister
   P.O.BOX 113816
   26/1, M. Thores Emb.,
   Moscow, USSR (telegram)
2. Telex N 131139 Raakoc SU
   KIEV Mr. S.Kuchuk-Yatsenko
   Deputy Director
   E.O.Paton Welding Institute

Very Yours Truly

Deputy Minister Никитин B.NIKITIN

CF

1600.02

Alberta

OIL SANDS TECHNOLOGY
AND RESEARCH AUTHORITY

403/427-7623
Fax 403/422-9112
Telex 037-3519
500 Highfield Place
10010 - 106 Stree
Edmonton, Alberta, Canada
T5J 3L8

November 16, 1989

Mr. L. Filimonov
Minister
P.O. Box 113816
26/1, M. Thores Emb.
Moscow, U.S.S.R.

Sent Via Special Delivery

Dear Mr. Filimonov:

We are in receipt of your recent letter which was brought to Dr. Redford by Mr. Vladimir Reitman on his return from the Soviet Union.

As you aware, Alberta has a vast complex of pipelines installed in climatic conditions similar to those found in the Soviet Union and they are used for moving a wide variety of materials. Therefore, Alberta has had to develop the technology for the installation and safe operation of these facilities.

AOSTRA would be very pleased to set up a profitable itinerary during the stay of your experts in Alberta to ensure that you meet the right people with technology in this area. Please let us know the dates that you propose to be in Alberta and the length of time you are able to stay (suggest a minimum of one week) and we will look after the arrangements from there.

Looking forward to your visit to Alberta, I remain

Yours sincerely,

WJYurko

W. J. Yurko
Chairman and
Chief Executive Officer

c.c. Mr. S. Kuchuk-Yatsenko (Sent Via Telex)
V. Reitman
P. Ross

DAR/ph

APPENDIX 5

Krasnodar

1. Brochure of MNTK (Nefteotdacha) manufacturing plant "Neftetermash", outlining specification of their steam-gas injection and other equipment.
2. Paper — "High Viscosity Oil Recovery from Carbonate Reservoirs by Thermal Methods".

MNTK
NEFTEOTDACHA

ОПЫТНО-ЭКСПЕРИМЕНТАЛЬНЫЙ
МАШИНОСТРОИТЕЛЬНЫЙ ЗАВОД
„НЕФТЕТЕРМАШ"

SCIENCE AND INDUSTRY

SCIENCE AND INDUSTRY ADVANCED FORM OF INTEGRATION

MNTK "Nefteotdacha"—interbranch scientific technological complex, organized in 1985. The main activity of MNTK is concentrated on fundamental scientific and technical problems the aim of which is to enhance ultimate oil recovery.

Complex has a tremendous science and technical potential, its experts are working in the following fields:

— Theoretical Physical Chemistry, Thermodynamics and Microbiology,

— Oil Production Technology,

— Modern hardware and components design,

— New chemicals design,

— Production Service of Complicated Technical hardware and components.

The total number of research and production personnel is over 16500 people.

MNTK "Nefteotdacha"—engineering and consultations for oil and oil-gas fields development:

1. Design consultations.
2. Working out design plans and specifications.
3. Author's supervision for fields development.
4. Analysis of field development and recommendations for its improvement.
5. Oil recovery prediction.
6. Complex thermo- and hydrodynamic studies and their interpretation.
7. Laboratory investigations for specific projects of the Customer.
8. Consultations and training for operating and production personnel by MNTK experts.
9. Training in the USSR of Customer's operating and production personnel.
10. Organisation and holding of scientific and technical seminars and symposia.

Apollinari Y. Vlasyuk

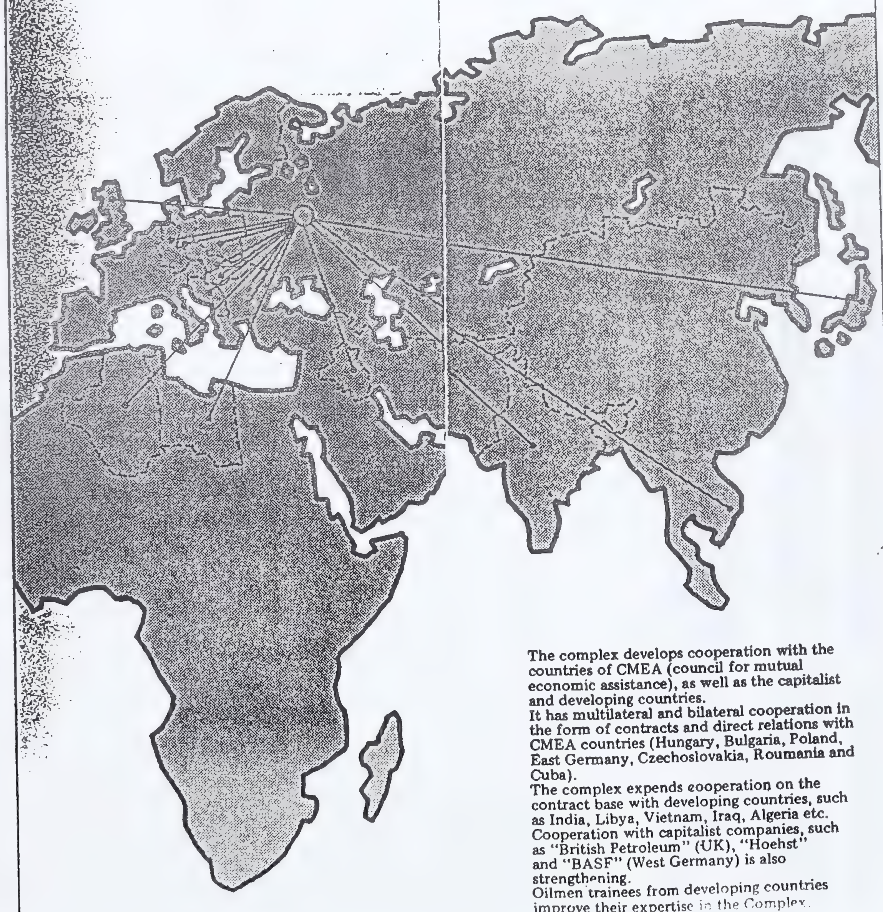
Chief Engineer of
«Neftetermmash» plant

nistry for Oil Industry
ersettoral Scientific
Technical Complex
fteotdacha
search & Production
sociation Soyuztermneft

38, Sovetskaya St.,
Settlement Chernomorski,
Severski Region,
Krasnodar Territory,
353243, USSR

ВЛАСЮК
Аполлинарий Еремеевич
Гл. инженер — начальник
специализированного конструкторско-
те нологического бюро опытно-
экспериментального машиностроительного
завода «Нефтетермаш»

INTERNATIONAL COOPERATION



The complex develops cooperation with the countries of CMEA (council for mutual economic assistance), as well as the capitalist and developing countries.

It has multilateral and bilateral cooperation in the form of contracts and direct relations with CMEA countries (Hungary, Bulgaria, Poland, East Germany, Czechoslovakia, Roumania and Cuba).

The complex expends cooperation on the contract base with developing countries, such as India, Libya, Vietnam, Iraq, Algeria etc.

Cooperation with capitalist companies, such as "British Petroleum" (UK), "Hoehst" and "BASF" (West Germany) is also strengthening.

Oilmen trainees from developing countries improve their expertise in the Complex.

Specialists of the Complex participate in

PARTICIPANTS

Scientific and research organizations and production enterprises of Minnefteprom of the USSR are parts of MNTK:

— All Union Oil and Gas Research Institute (VNII), Moscow — head organization,

— Three research and production associations (NPO):
"Soyuztermneft" (Krasnodar),
"Soyuzneftepromhim" (Kasan),
"Soyuznefteotdacha" (Ufa),

Experimental oil and gas production association (OENGDY) "Tatneftebitum" (Leninogorsk).

List of other participants:

7 Institutes of the Academy of Sciences of the Soviet Union

— Institute of High Temperatures, IVTAN, Moscow;

— Institute of Physical Chemistry, IFH, Moscow;

— Institute of Oil and Gas Problems, IPNG, Moscow;

— Institute of Chemical Physics, IHF, Moscow;

— Institute of Mechanics' Problems, IPM, Moscow;

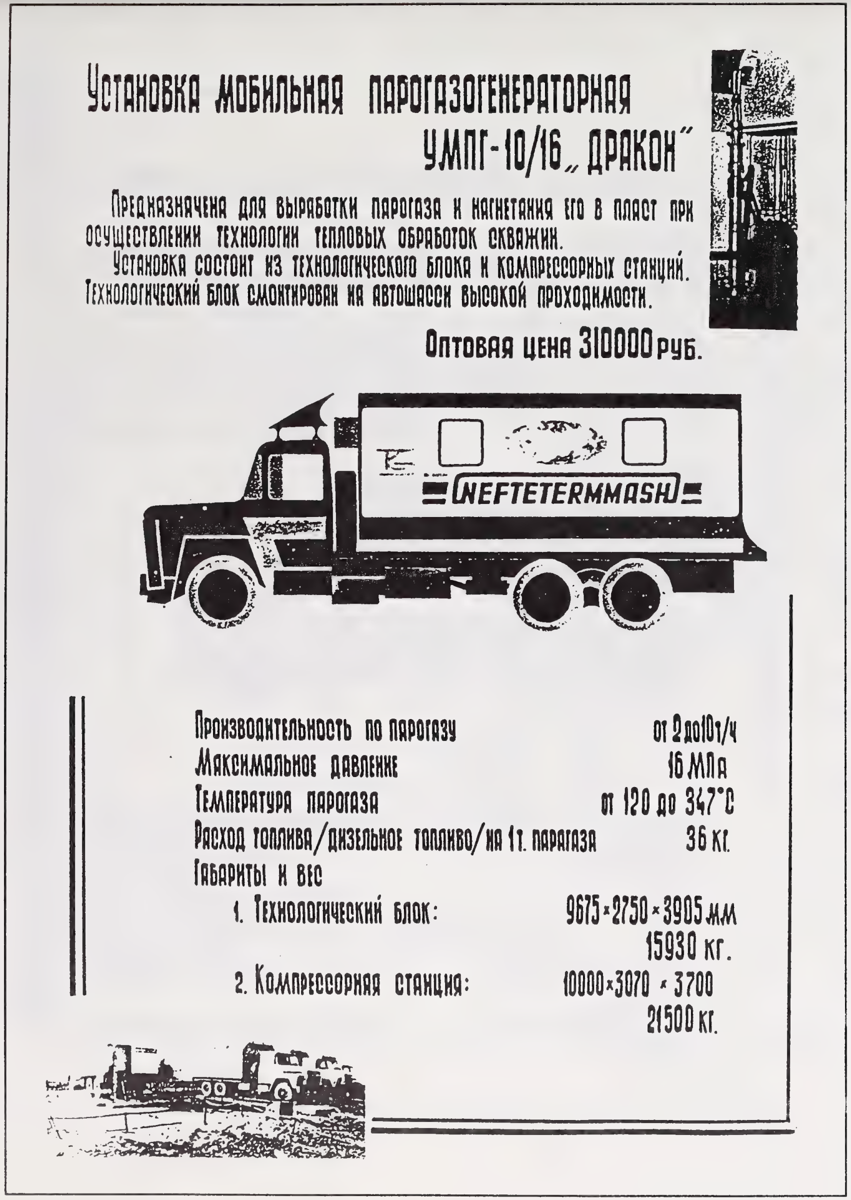
— Siberian division of Oil Chemistry Institute, IH, Tomsk;

— Deep Oil and Gas Field Problems Institute, Baku;

9 scientific and research institutes of other ministries;

3 Higher educational institutions of the State Committee for People's Education.

For all additional information, please, contact MNTK
"NEFTEOTDACHA" 10, Dmitrovsky Proezd, Moscow, 125422, USSR



NEFTETERMMASH

Установка мобильная парогазогенераторная УМПГ-10/16 „Дракон"

Предназначена для выработки парогаза и нагнетания его в пласт при осуществлении технологии тепловых обработок скважин.

Установка состоит из технологического блока и компрессорных станций. Технологический блок смонтирован на автошасси высокой проходимости.

Оптовая цена 310000 руб.

Производительность по парогазу	от 2 до 10 т/ч
Максимальное давление	16 МПа
Температура парогаза	от 120 до 347°С
Расход топлива/дизельное топливо/на 1т. парагаза	36 кг.
Габариты и вес	
1. Технологический блок:	9675×2750×3905 мм 15930 кг.
2. Компрессорная станция:	10000×3070×3700 21500 кг.

Mobil Gas-Steam Generator Unit
UMPG-10/16 "Dragon"

For production of gas-steam mixture and injection into deposit for thermal conditioning. It consists of technological unit and compressor station. Technological unit is mounted on an off-road vehicle.

Price inisde U.S.S.R. – 310,000 rubles

Mixture production	2–10 t/hr
Max pressure	16 mPa
Temperature of mixture	120–347°C
Fuel consumption $\left(\frac{\text{kg of diesel}}{\text{1 T of mixture}}\right)$	36 km/t

Dimensions and weight

1. Technological	9675 x 2750 x 3905 mm 15,930 kg
2. Compressor station	10,000 x 3070 x 3700 mm 21,500 kg

УСТАНОВКА МОБИЛЬНАЯ ПАРОГАЗОГЕНЕРАТОРНАЯ УМПГ 10/16 "ДРАКОН"

Предназначена для выработки парогазового теплоносителя и нагнетания его в пласт при осуществлении теплового воздействия на нефтяные пласты комбинированным парогазовым теплоносителем.

Установка состоит из технологического блока и двух передвижных компрессорных станций. Все блоки смонтированы на автошасси высокой проходимости.

Производительность по парогазу	от 1,25 до 10 т/ч
Температура парогаза	от 120 до 350°С
Максимальное давление	16 МПа
Удельный расход на 1 т парогаза при	350°С
топливо (дизельное)	36 кг
воздух	464 кг
вода	500 кг
Габариты и вес блоков:	
Технологический блок:	9520 x 2750 x 3730 мм 18000 кг
Станция компрессорная	10000 x 3070 x 3700 21500 кг

MOVABLE STEAM AND GAS GENERATOR PLANT UMPG-10/16 "DRAGON"

Used for steam and gas mixture production. It's a component of an equipment set for thermal reservoir stimulation by a combined steam and gas heat carrier.

This plant consists of a technological unit and two movable compressor stations. All units are mounted on a cross-country chassis.

Steam and gas output	1,25–10 ton/hour
Steam and gas temperature	120–350°C
Max. pressure	16 MPa
Specific consumption per 1 ton of steam and gas mixture at	350°C
fuel	36 kg
air	464 kg
water	500 kg
The unit's dimentions and weight:	
– technological unit	9520 x 2750 x 3730 mm 18000 kg
– compressor station	10000 x 3070 x 3700 mm 21500 kg

Разработчик-изготовитель – НПО "Союзтермнефть" Manufacturer – NPO "Sojuztermneft"

УСТАНОВКА МОБИЛЬНАЯ ПАРОГЕНЕРАТОРНАЯ УМП-6/16 „ГЕЙЗЕР"

ПРЕДНАЗНАЧЕНА ДЛЯ ВЫРАБОТКИ НАСЫЩЕННОГО ПАРА И НАГНЕТАНИЯ ЕГО В ПЛАСТ ПРИ ОСУЩЕСТВЛЕНИИ ТЕХНОЛОГИИ ПАРОТЕПЛОВЫХ ОБРАБОТОК СКВАЖИН.
УСТАНОВКА СОСТОИТ ИЗ ТЕХНОЛОГИЧЕСКОГО БЛОКА И КОМПРЕССОРНОЙ СТАНЦИИ НА ПРИЦЕПЕ. ТЕХНОЛОГИЧЕСКИЙ БЛОК СМОНТИРОВАН НА АВТОШАССИ ВЫСОКОЙ ПРОХОДИМОСТИ.

ОПТОВАЯ ЦЕНА – 290.000 РУБЛЕЙ.

ПРОИЗВОДИТЕЛЬНОСТЬ ПО ПАРУ	ОТ 3 ДО 6 Т/Ч
МАКСИМАЛЬНОЕ ДАВЛЕНИЕ	16 МПА
ТЕМПЕРАТУРА ПАРА	347° С
СТЕПЕНЬ СУХОСТИ НЕ БОЛЕЕ	0,8
РАСХОД ТОПЛИВА /ДИЗЕЛЬНОЕ ТОПЛИВО/ НА 1Т. ПАРА	52 КГ
ГАБАРИТЫ И ВЕС	
1. ТЕХНОЛОГИЧЕСКИЙ БЛОК:	9675×2750×3905 ММ 15930 КГ
2. КОМПРЕССОРНАЯ СТАНЦИЯ:	8355×2870×3060 ММ 11580 КГ

UMPG-6/16 "Geyser"

For production of saturated steam and injection into deposit for thermal conditioning. It consists of technological unit and compressor station in a trailer. Technological unit is mounted on off-road vechicle.

Price inisde U.S.S.R. – 310,000 rubles

Mixture production	3–6 t/hr
Max pressure	16 mPa
Steam temperature	347°C
Steam quality, no more than	0.8
Fuel consumption $\left(\frac{\text{kg of diesel}}{\text{1 T of mixture}}\right)$	52 kg

Dimensions and weight

1. Technological	9675 x 2750 x 3905 mm 15,930 kg
2. Compressor station	8355 x 2870 x 3060 mm 11,580 kg

УСТАНОВКА МОБИЛЬНАЯ ПАРОГЕНЕРАТОРНАЯ УМП-6/16 "ГЕЙЗЕР"

Предназначена для выработки насыщенного пара и нагнетания его в пласт при осуществлении технологии паротепловых обработок скважин.

Установка состоит из технологического блока и компрессорной станции на прицепе. Технологический блок смонтирован на автошасси высокой проходимости.

Производительность по пару	от 3 до 6 т/ч
Максимальное давление	16 МПа
Температура пара	347°С
Степень сухости не более	0,8
Расход топлива (дизельное топливо) на 1 т пара	52 кг
Габариты и вес	
1. Технологический блок:	9675 x 2750 x 3905 мм
	15930 кг
2. Компрессорная станция:	8355 x 2870 x 3060 мм
	11580 кг

MOVABLE STEAM GENERATOR PLANT UMP-6/16 "GEYZER"

Used for saturated steam production. It's a component of an equipment set for cyclic steam stimulation technique.

The plant consists of a technological unit and a compressor station. All units are mounted on a cross-country chassis.

Steam output	from 3 to 6 ton/hour
Max. pressure	16 MPa
Steam temperature	347°C
Steam dryness	0,8
Fuel consumption per 1 ton of steam generation	52 kg
The unit's dimentions and weight:	
– Thechnological unit	9675 x 2750 x 3905 mm
	15930 kg
– Compressor station	8355 x 2870 x 3060 mm
	11580 kg

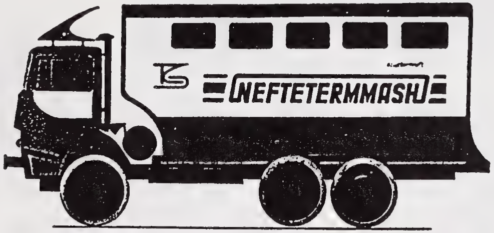
Разработчик-изготовитель – НПО "Союзтермнефть"

Manufacturer – NPO "Sojuztermneft"

СЕРВИСНЫЙ БЛОК

Предназначен для проживания членов экипажа теплогенерирующих установок в комфортных условиях. Конструктивно состоит из двух отсеков /спальный и бытовой/, на шасси автомобиля КамАЗ 4310

Оптовая цена 60000 рублей



Спальный отсек

Спальные места	4
Шкафы для одежды	2
Кондиционер БК-1500	1
Стол рабочий	1

Бытовой отсек

Холодильник	1
Мойка	1
Душ	1
Шкаф для верхней одежды	1
Комплект кухонных принадлежностей	1

Освещение:	рабочее	от сети 220В 50Гц.
	резервное	от бортовой сети автомобиля
Отопление	электрическое	от сети 220в. 50Гц.

Accomodation Unit

For accomodation of the crew of the thermal units in comfortable conditions, consists of two parts (sleeping and living facilities) and is mounted on off-road truck KaMaz 4310.

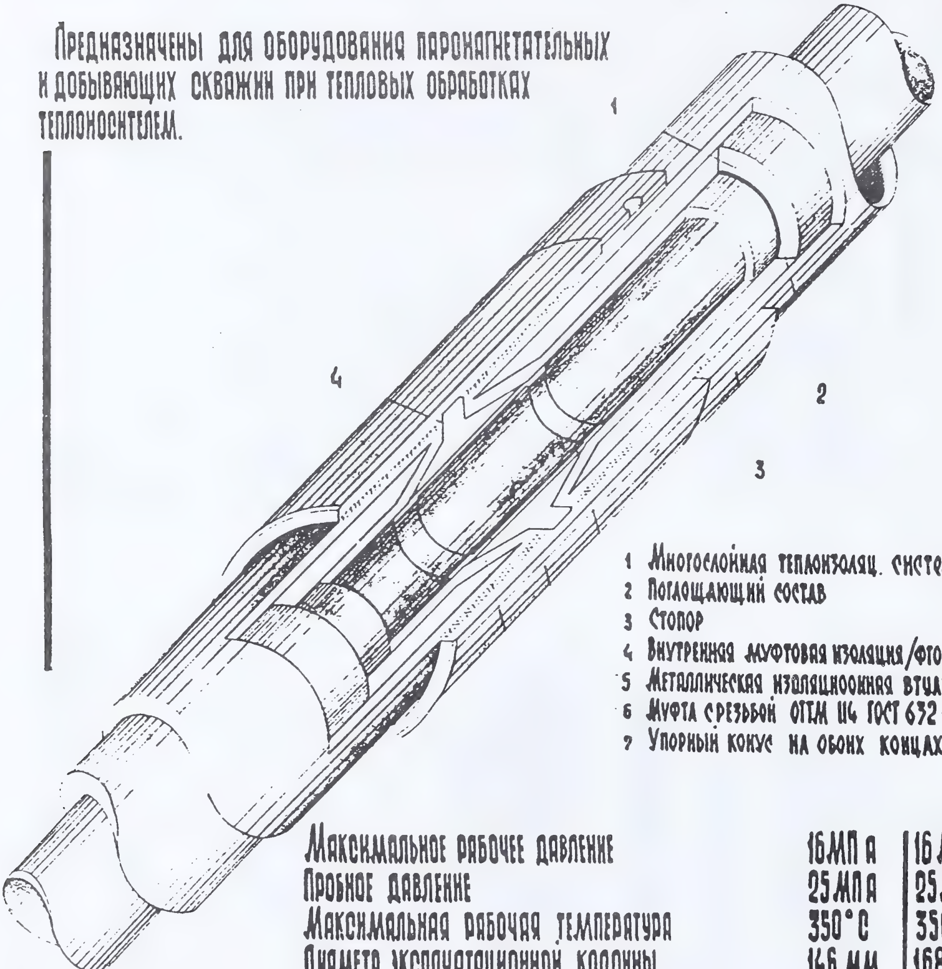
Price inisde U.S.S.R. – 60,000 rubles

Sleeping compartment	
Sleep places	4
Closets	2
Air conditioner	1
Work table	1

Living compartment	
Refrigerator	1
Sink	1
Shower	1
Closet	1
Kitchen wire	1
Light	220 V
Reserve light	12 V
Heating	220 V

ТРУБЫ ТЕПЛОИЗОЛИРОВАННЫЕ ТТ-48/89-350-1, ТТ-73/114-350-1

Предназначены для оборудования паронагнетательных и добывающих скважин при тепловых обработках теплоносителем.



1 Многослойная теплоизоляц. система
2 Поглощающий состав
3 Стопор
4 Внутренняя муфтовая изоляция /фторопласт/
5 Металлическая изоляциоонная втулка
6 Муфта с резьбой ОТТМ 114 ГОСТ 632-80
7 Упорный конус на обоих концах

Максимальное рабочее давление	16МПа	16 МПа
Пробное давление	25МПа	25МПа
Максимальная рабочая температура	350°С	350°С
Диаметр эксплуатационной колонны	146 мм	168 мм
Наружный диаметр наружной трубы	89 мм	114 мм
Наружный диаметр муфты	107 мм	132 мм
Внуренний проходной диаметр	40 мм	62 мм
Максимальная осевая нагрузка	350 кН	350 кН
Потери тепла по длине колонны	150 Вт/м	150 Вт/м
Масса погонного метра	19,8 кг.	32,3 кг.
Длина секции	от 8 до 9 м	от 8 до 9 м

ТРУБЫ ТЕПЛОИЗОЛИРОВАННЫЕ ТТ-48/89-350-1 ТТ-73/II4-350-I

Предназначены для оборудования паронагнетательных и добывающих скважин при тепловых обработках теплоносителем.

Конструкция по типу труба в трубе, предварительно напряженная с экранно-вакуумной теплоизоляцией.

Максимальное рабочее давление	16 МПа	I6 МПа
Пробное давление	25 МПа	25 МПа
Максимальная рабочая температура	350°С	350°С
Диаметр эксплуатационной колонны	146 мм	I68 мм
Наружный диаметр наружной трубы	89 мм	II4 мм
Наружный диаметр муфты	107 мм	I32 мм
Внутренний проходной диаметр	40 мм	62 мм
Максимальная осевая нагрузка	350 кН	350 кН
Потери тепла по длине колонны	150 ВТ/м	I50 ВТ/м
Масса погонного метра	19,8 кг	32,3 кг
Длина секции	от 8 до 9 м	от 8 до 9м

THERMO-INSULATED PIPES TT-48/89-350-1 TT-73/II4-350-I

Used for steam injectors and producers during oil field thermal stimulation. It's a double-pipe (inner pipe is prestressed) with screen-vacuum thermal insulation.

Max. working pressure	16 MPa	I6 MPa
Test pressure	25 MPa	25 MPa
Max. working temperature	350°C	350°C
Flow string diameter	146 mm	I68 мм
Outer pipe outside diameter	89 mm	II4 мм
Outside coupling diameter	107 mm	I32 мм
Inside passage diameter	40 mm	62 мм
Max. axial load	350 Kn	350 Kn
Heat losses along the pipe length	150 w/m	I50 w/m
Mass of running meter	19,8 kg	32,3kg
Section length	from 8 to 9 m	8...9 m

Разработчик-изготовитель – НПО "Союзтермнефть"

Manufacturer – NPO "Sojuztermneft"

СБОРНО-РАЗБОРНЫЙ ТЕПЛОИЗОЛИРОВАННЫЙ НАЗЕМНЫЙ ПАРОПРОВОД ПМ-65-16-350

Предназначен для подачи теплоносителя от энергетических установок к скважинам, разрабатываемым тепловыми методами. Собирается на месте эксплуатации из отдельных секций с установкой на штатные нестационарные опоры. Снабжен угольниками для монтажа переходов над проезжей частью дороги, поворотными узлами для искривления оси паропровода от 0 до 15° в любой плоскости.

Максимальное давление теплоносителя	16 МПа
Максимальная температура теплоносителя	350°C
Условный диаметр паропровода	60 мм
Температура наружной поверхности паропровода	50°C
Длина одной секции	6 м
Максимальная длина одного комплекта	300 м
Вес одного погонного метра паропровода	30 кг

COLLAPSIBLE THERMO-INSULATED SURFACE STEAM PIPE-LINE MP-65-16-350

Used for heat carrier transportation from generator plants to the wells, developed by thermal methods.

It is mounted at production site on non-stationary supports. The pipe-line is supplied by elbows to make cross-overs above the roads and turning joints to steam pipe-line axle deviation from 0° to 15° in any plane.

Max. heat carrier pressure	16 MPa
Max. heat carrier temperature	350°C
Nominal steam pipe-line diameter	60 mm
Pipe-line outside surface temperature	50°C
Single section length	6 m
Max. single set length	300 m
Running meter weight	30 kg

Разработчик-изготовитель — НПО "Союзтермнефть"

Manufacturer — NPO "Sojuztermneft"

ПАКЕР ТЕРМОСТОЙКИЙ ПТ-146

Предназначен для герметизации затрубного пространства паронагнетательных скважин при закачке теплоносителя.

Максимальное давление теплоносителя	16 МПа
Максимальная температура теплоносителя	350°C
Диаметр обсадной колонны	146 мм
Диаметр пакера	118 мм
Длина пакера	4349 мм
Вес пакера	175 кг

THERMAL RESISTANT PACKER PT-146

Used for annulus sealing in steam injectors during heat carrier injection.

Max. heat carrier pressure	16 MPa
Max. heat carrier temperature	350°C
Outside casing diameter	146 mm
Packer diameter	118 mm
Packer length	4349 mm
Packer weight	175 kg

Разработчик-изготовитель – НПО "Союзтермнефть"

Manufacturer – NPO "Sojuztermneft"

ФИЛЬТР ПРОВОЛОЧНЫЙ ПРОФИЛИРОВАННЫЙ ФПП-146/168

Предназначен для оборудования забоя пескопроявляющих скважин. Отличается повышенной точностью и стабильностью рабочего зазора, прочностью крепления витков намотки и высокой коррозионной и эррозионной устойчивостью.

Рабочий зазор фильтра	0,25 мм
Наружный диаметр фильтрующей секции	102 мм
Внутренний проходной диаметр секции	76 мм
Скважность фильтрующей поверхности	10%
Длина фильтрующей секции	1690 мм
Вес комплекта из 10 секций (ориентировочно)	650 кг

WIRE-WRAPPED SHAPED SCREEN FPP-146/168

Used for bottom-hole installation in sand producing wells. Its working clearance is of high precision and stability, rigid coils fixing as well as high corrosion and erosion stability.

Screen working clearance	0,25 mm
Screen section outside diameter	102 mm
Screen section inside passage diameter	76 mm
Screen surface porosity	10%
Screen section length	1690 mm
10-section set weight	650 kg

Разработчик-изготовитель – НПО "Союзтермнефть"

Manufacturer – NPO "Sojuztermneft"

АРМАТУРА ТЕРМОСТОЙКАЯ ПАРОВАЯ АТП-65-16-350-УХЛ1

Предназначена для герметизации устья паронагнетательной скважины. Обеспечивает управление потоком теплоносителя и компенсацию температурных удлинений наземного теплоизолированного паропровода и внутрискважинных теплоизолированных труб, при этом габаритные размеры арматуры не меняются.

Арматура позволяет устанавливать лубрикатор для спуска глубинных приборов и проведения исследований.

Максимальное давление теплоносителя	16 МПа
Максимальная температура теплоносителя	350°C
Условный проход	65 мм
Температура окружающей среды от	–60 до +40°C
Диаметр обсадной колонны	168 мм
Наружный диаметр колонны теплоизолированных труб	114 мм
Габариты: длина	– 1100 мм
ширина	– 900 мм
высота	– 2700 мм
Вес арматуры	– 1200 кг

HEAT RESISTANT FITTING ATP-65-16-350-UHL-1

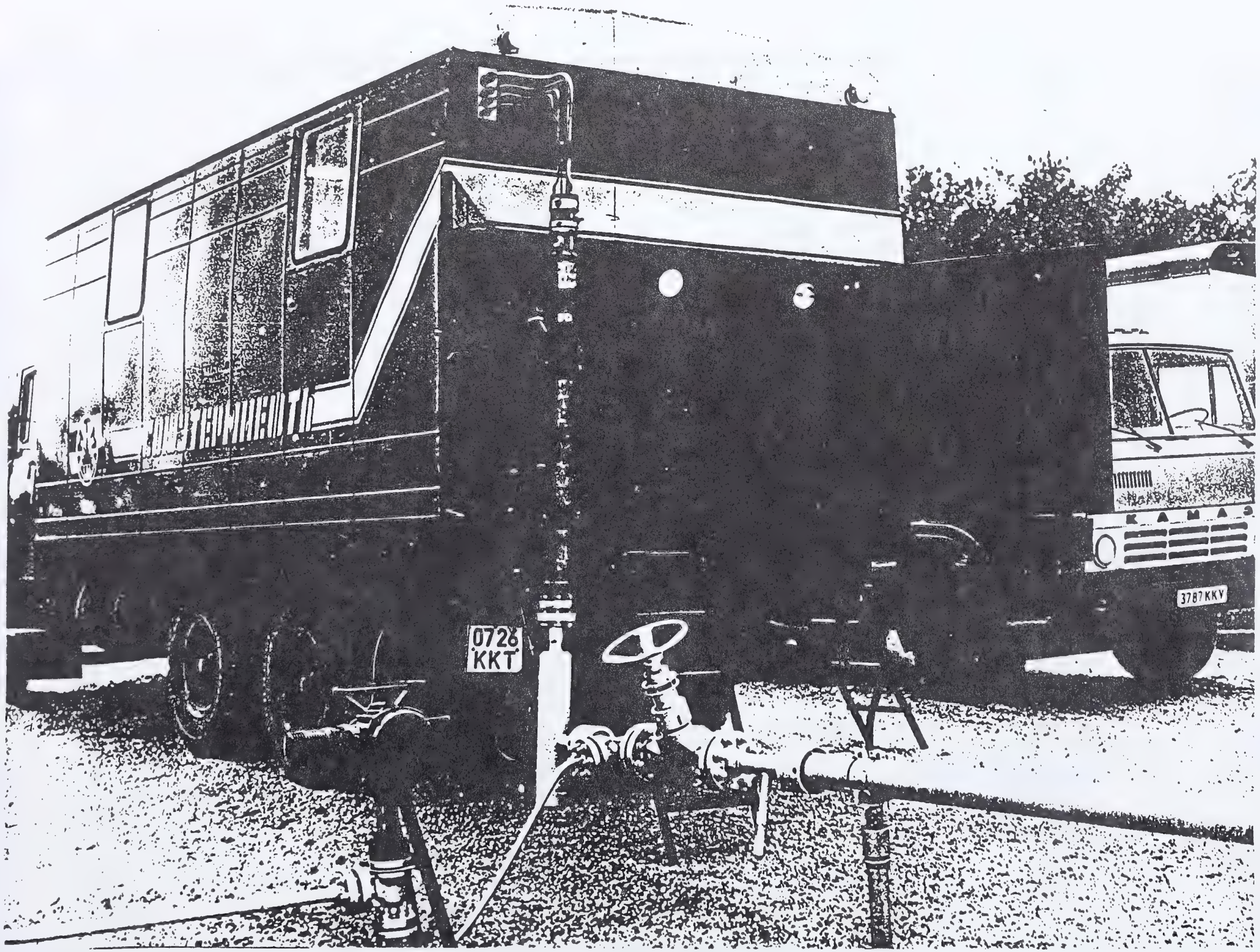
Used for wellhead sealing and a heat carrier flow control. Provides pipes temperature extention compensation without unit's dimension changing.

There is a lubricator in fitting set, used for running of down-hole devices and equipment into the well.

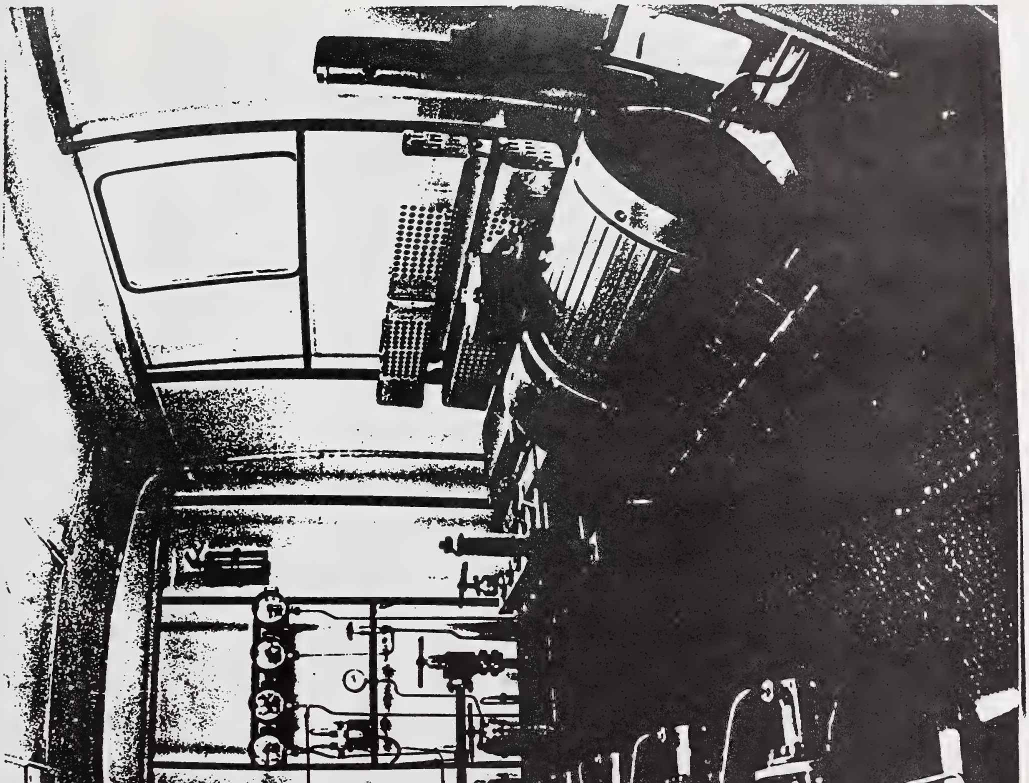
Max. heat carrier pressure	16 MPa
Max. heat carrier temperature	350°C
Nominal passage	65 mm
Ambient temperature	from –60 to 45°C
Casing diameter	168 mm
Thermo-insulated outside pipe diameter	114 mm
Fitting dimentions: length	– 1100 mm
width	– 900 mm
heigth	– 2700 mm
Weight	– 1200 kg

Разработчик-изготовитель – НПО "Союзтермнефть"

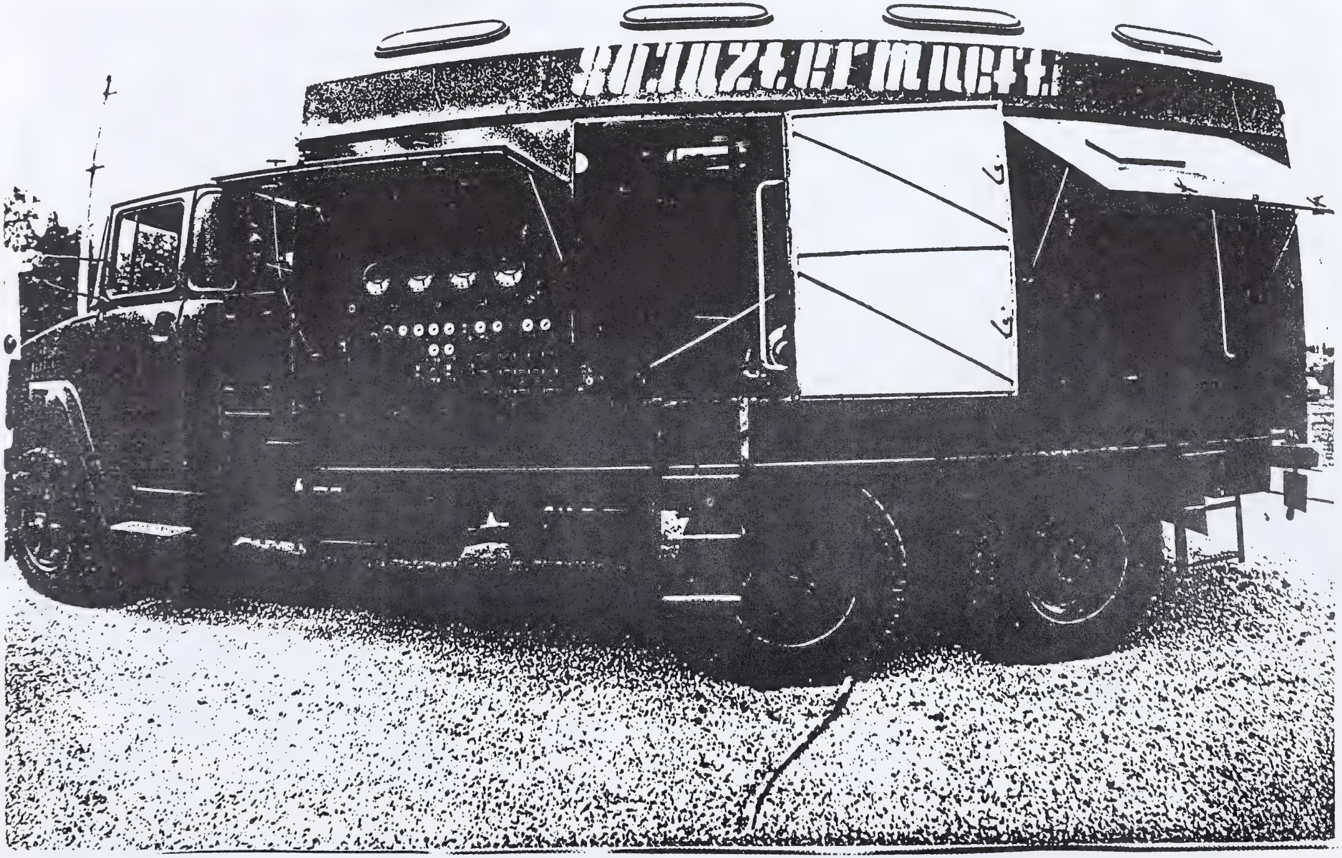
Manufacturer – NPO "Sojuztermneft"



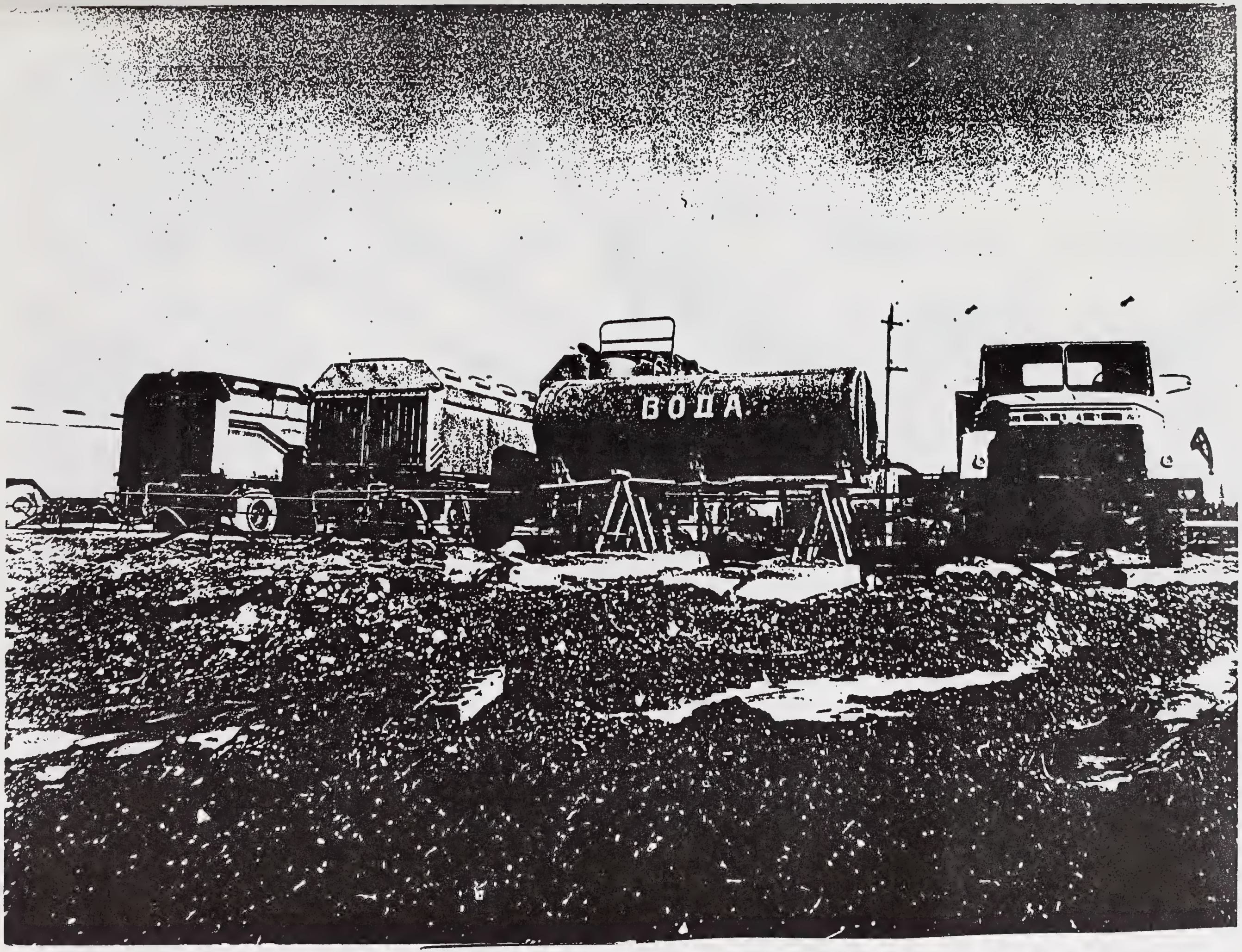
Well treatment setup using "Dragon" unit



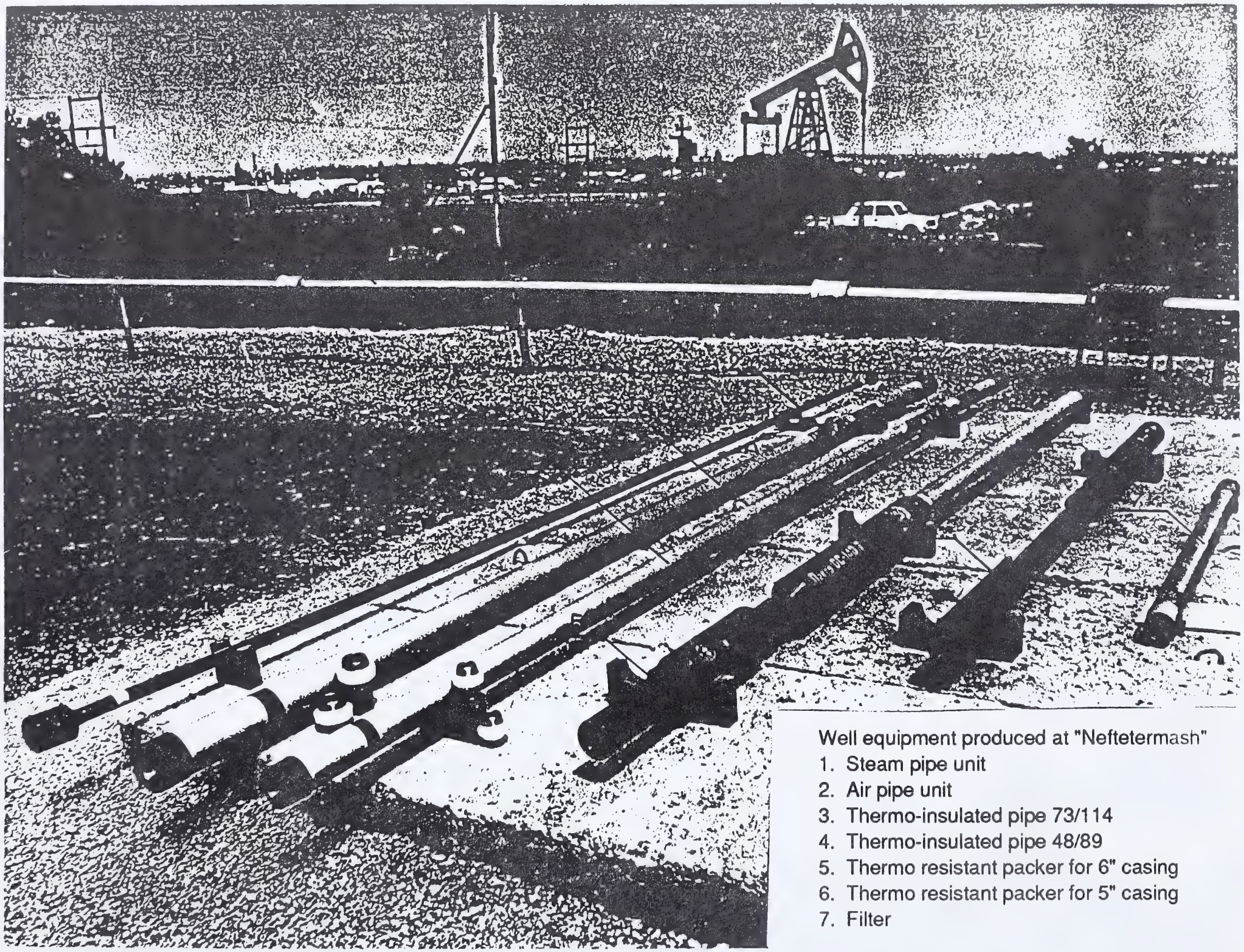
General view of technological unit inside "Dragon"



Compressor unit of "Dragon"

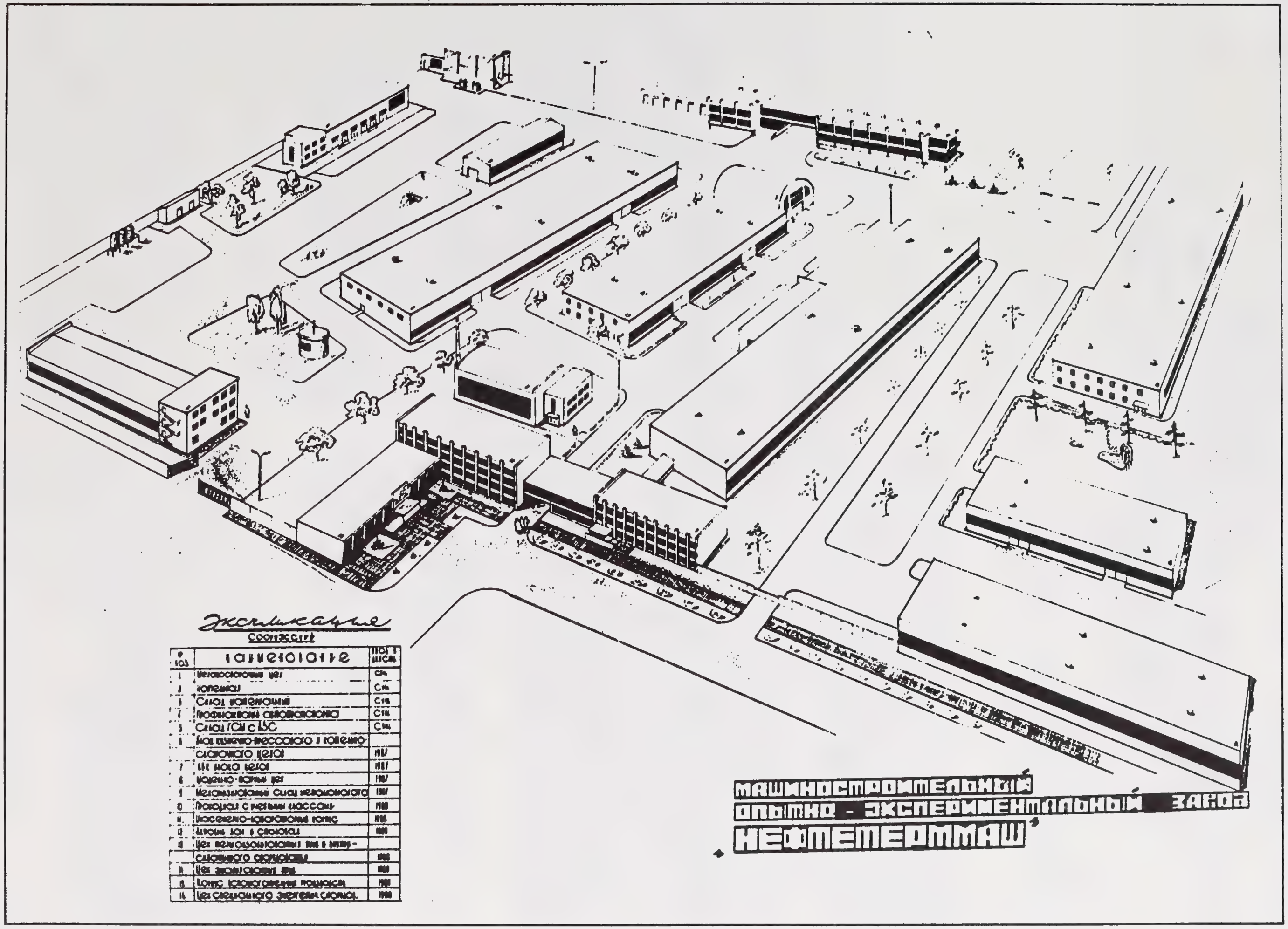


Mobile steam-gas generator unit UMPG 10/16 "Dragon"



Well equipment produced at "Neftetermash"

1. Steam pipe unit
2. Air pipe unit
3. Thermo-insulated pipe 73/114
4. Thermo-insulated pipe 48/89
5. Thermo resistant packer for 6" casing
6. Thermo resistant packer for 5" casing
7. Filter



Экспликация

сооружений

№ поз	Наименование	[illegible]
1	Механосборочный цех	Сущ.
2	Котельная	Сущ.
3	Склад материальный	Сущ.
4	Профилакторий автотранспорта	Сущ.
5	Склад ГСМ с АЗС	Сущ.
6	Блок кузнечно-прессового и котельно-сварочного цехов	1987
7	АБК новых цехов	1987
8	[illegible] цех	1987
9	Механизированный склад металлопроката	1987
10	Проходная с учебными классами	1988
11	Инженерно-лабораторный корпус	1988
12	[illegible]	[illegible]
13	Цех [illegible]	[illegible]
14	Цех [illegible]	[illegible]
15	Корпус [illegible]	[illegible]
16	Цех [illegible]	[illegible]

Alberta
ECONOMIC DEVELOPMENT
AND TRADE
Trade and Investment Division

11th Floor, Sterling Place, 9940 - 106 Street, Edmonton, Alberta, Canada T5K 2P6 403/427-4809 Telex 037-2197 Telefax 403/422-9127

November 28, 1989

Mr. Alexander G. Garushev
Deputy Director General
Ministry for Oil Industry
54 Krasnaya Street
Krasnodar 350610
U.S.S.R.

Dear Mr. Garushev:

Enclosed please find an information package regarding the National Petroleum Show (NPS) in Calgary, June 12-14, 1990. This package provides you with information about the show as well as the market potentials in the North American continent.

I would like to extend an invitation to your organization to participate in this event. On behalf of the Government of Alberta, I offer our assistance with any logistical arrangements which may be required for your participation in NPS '90.

I am certain that you will find NPS a truly world class event and a must for all organizations involved in the oil and gas industry who wish to be active in the North American market.

Should you decide to participate in NPS '90, please let me know how we can be of assistance either with your exhibition in this show or any meetings with Alberta based organizations that may be of interest to you.

Yours truly,

B. Sadre-hashemi

Behrooz Sadre-Hashemi
Director
TRADE SHOW PROMOTION

/gmb

attachment

bcc: H, Bergman
W, Brandow
J, Yurko

HIGH VISCOSITY OIL RECOVERY FROM CARBONATE RESERVOIRS BY THERMAL METHODS

D.G. Antoniadi, V.F. Budnikov, and A.R. Garushev, Research & Production Association Soyuztermneft, Krasnodar, USSR

(PAPER NO. 223)

ABSTRACT

The problem of high-viscosity oil recovery from carbonate reservoirs is of great interest.

A number of pilot and semi-commercial projects of thermal oil recovery from carbonate fractured porous reservoirs by in situ combustion and bed steam stimulation have been carried out in the USSR.

Generally, formations are represented by macro- and microporous reservoirs. Under these conditions the realized field experiments gave the following evidence:

— In carbonate reservoirs the development of the in situ combustion process generally takes place in macroporous reservoirs. As the combustion front velocity in macroporous channels is 50 cm/day or more, the thermodynamic process under these conditions is similar to an adiabatic process by its physical nature when heat isn't transferred to a microporous reservoir and the latter isn't heated.

— Cyclic steam stimulation of wells is recommended for high viscosity oil recovery from carbonate micro- and macroporous reservoirs at the first stage.

— Pattern cyclic steam stimulation is recommended for heating and displacement of oil from microporous reservoirs to macroporous ones at the second stage.

— At the third stage, after the oil displacement from microporous to macroporous reservoirs, its further advance through the formation can be assisted by cold or hot water and other hot agents.

The problem of high viscosity oil recovery from carbonate porous fractured reservoirs is urgent. It is commonly known that main oil reserves are confined to porous reservoirs. Injection of water, air and gases into a reservoir as secondary and tertiary methods for oil recovery hasn't been a success because the injected working agents move through high permeability macroporous reservoirs to producing wells, displacing oil mainly from these formations.

However, low permeability reservoirs are not swept by the injected working agents.

A number of thermal projects for oil recovery from carbonate fractured porous reservoirs have been carried out on pilot and semi commercial scale in the USSR such as Zybza and Borovskoye (depleted oil fields) and Usinskoye and Gremikhinskoye (new undeveloped oil fields) (Baybakov and Garushev, 1988).

In situ combustion and steam drive processes have been practiced. *In situ* combustion proved to be difficult in practice as the air-oxygen injected into the reservoir breaks through the macroporous channels to the producing wells and creates dangerous concentrations that cause explosions.

For instance, two pilot in situ combustion processes were practiced in the Zybza (Krasnodar territory) and Borovskoye (Kuibyshev territory) oil fields in formations of which contain micro- and macroporous reservoirs with permeability varying from 0.05 to 500 Darcies and higher (Figure 1).

The main geological and physical parameters of the Zybza pilot are given below:

Average depth	700 m
Average reservoir thickness	6 m
Oil saturation	45%
Oil viscosity	200 mPa•s

Figure 2 illustrates a pattern of injection, producing and observation wells. Three injection wells for creation of in situ combustion process are situated at 70 meters distance from each other. On both sides of the injection wells there are observation wells at 30–40 meters distance. Producing wells are 130–200 meters from the injection wells. Free penetration of air through macroporous channels into the producers was observed while injecting it into the formation.

Formation was ignited both by a gas burner and by an electric heater.

Rock failure and the resulting high permeability channels due to the creation of high temperature by the burner led

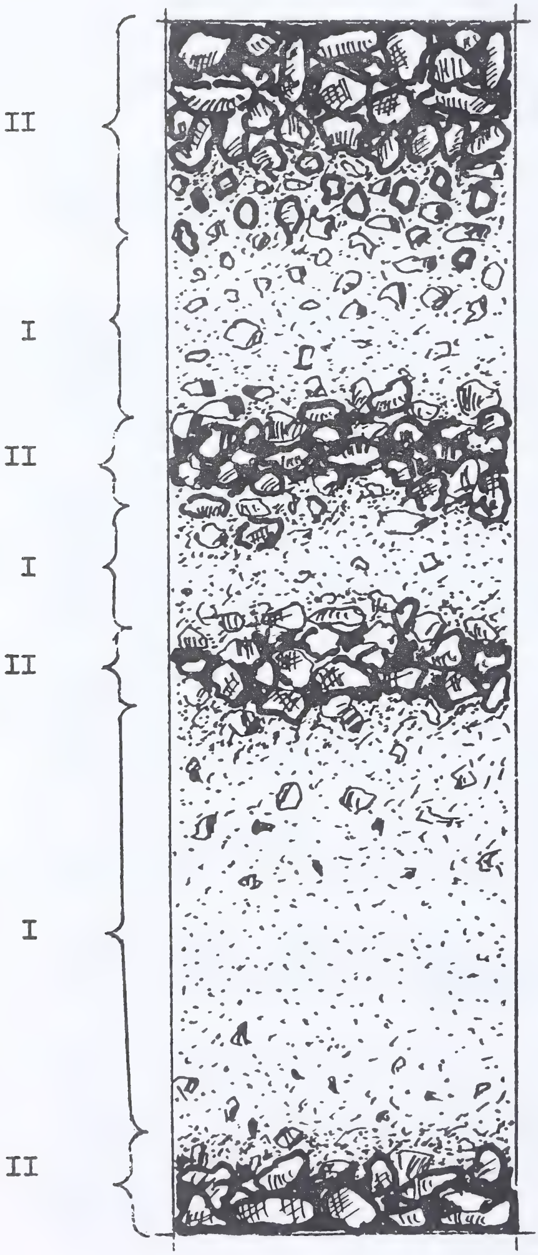


Figure 1. *Model of micro and macroporous reservoir; I - microporous; II - macroporous*

to plugging. This resulted in well injectivity reduction. So formation ignition was initiated and carried out with the electric heater, to allow control of the bottomhole temperature and prevent the rock failure and fracture plugging.

The electric heater was successfully used for the in situ ignition of oil. However the creation of combustion front with the electric heater was not a success because of air breakthrough into the producers causing an excessively explosive concentration of oxygen to take place. To reduce the air breakthrough into the producers, higher viscosity oil was injected into the injection wells and the ignition was repeated. These measures reduced to some extent the rate of oxygen breakthrough to the producing wells; however they were insufficiently effective. The main results of the in situ combustion practice are given below.

Heat of 50 MMkJ and 150,000 m^3 of air were injected into the formation with air consumption of about 3.5 Mm^3/day and at bottomhole heater temperature 350–400°C. Specific consumption of heat per meter of the formation thickness made about 8 MMkJ/meter.

It took 10–15 days to start the in situ combustion process. On igniting the formation the air consumption was increased to 12 Mm^3/day. The air injection pressure was increased from 0.1 to 2.5 mPa. The in situ combustion process lasted for about five months. During this period the oxygen content in end gases of the producers was 1–2.5%. Figure 3 illustrates the changes in oxygen and carbon dioxide content in the produced gas. In accordance with calculations, the combustion front would have advanced by one meter from the well bottom hole in free movement.

In practice it didn't happen. An intensive increase of the oxygen content in the produced fluids and a decay of the combustion process began after five months of oil displacement.

Similar results were also obtained while testing the in situ combustion process in carbonate reservoirs in the Borovskoye and Usinskoye oilfields.

SUMMARY

- — It is proved that in carbonate reservoirs the development of the *in situ* combustion process generally takes place in a macroporous reservoir. As the combustion front velocity in macroporous channels is 50 cm/day or more, the thermodynamic process under these conditions is similar to adiabatic by its physical nature, when heat isn't transferred to a microporous reservoir and the latter isn't heated.
- — A macroporous reservoir serves as a channel for a fast breakthrough. It makes a dangerously explosive concentration of oxygen/hydrogen mixture. This was

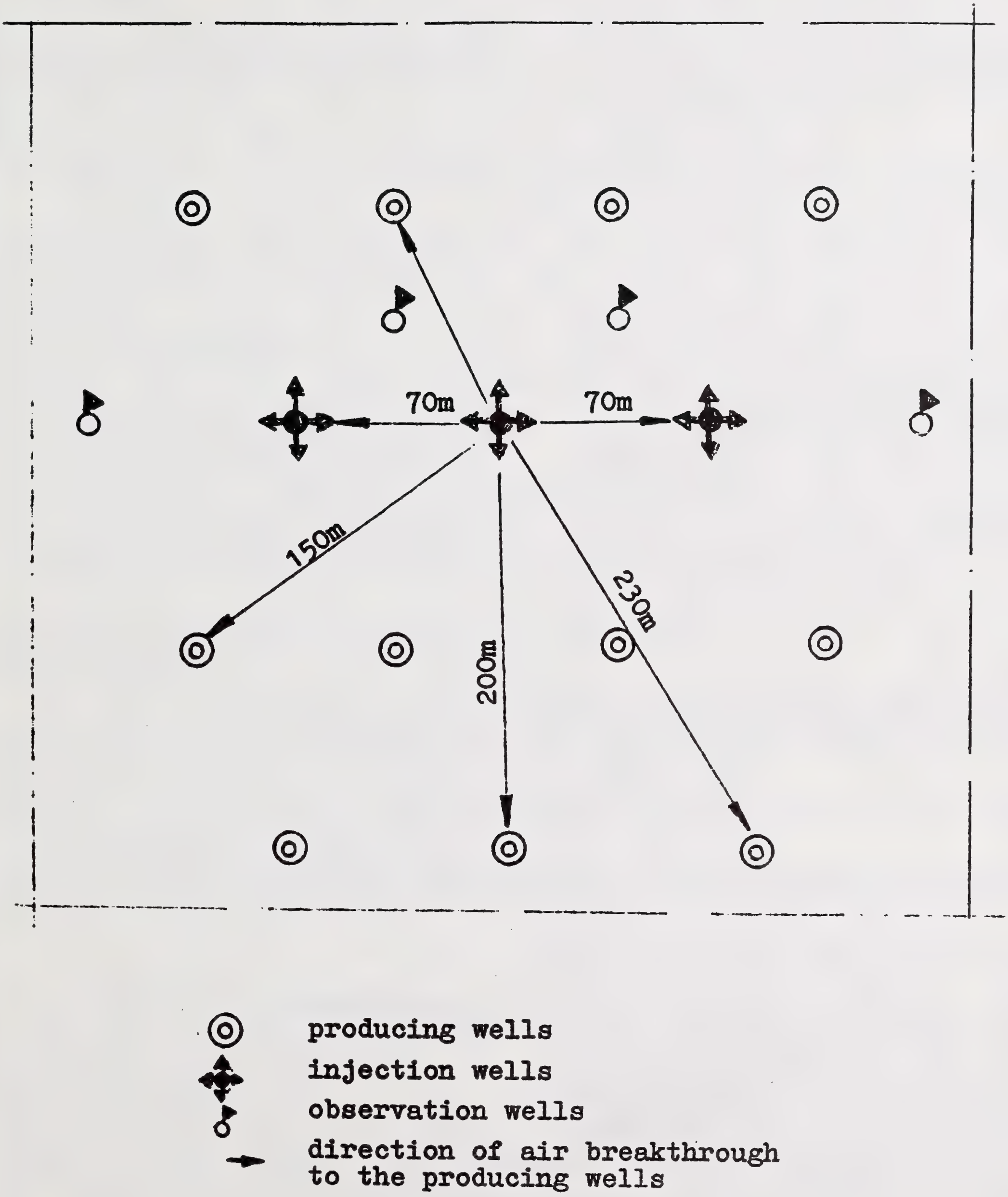


Figure 2. *Well pattern, Zybza field pilot project*

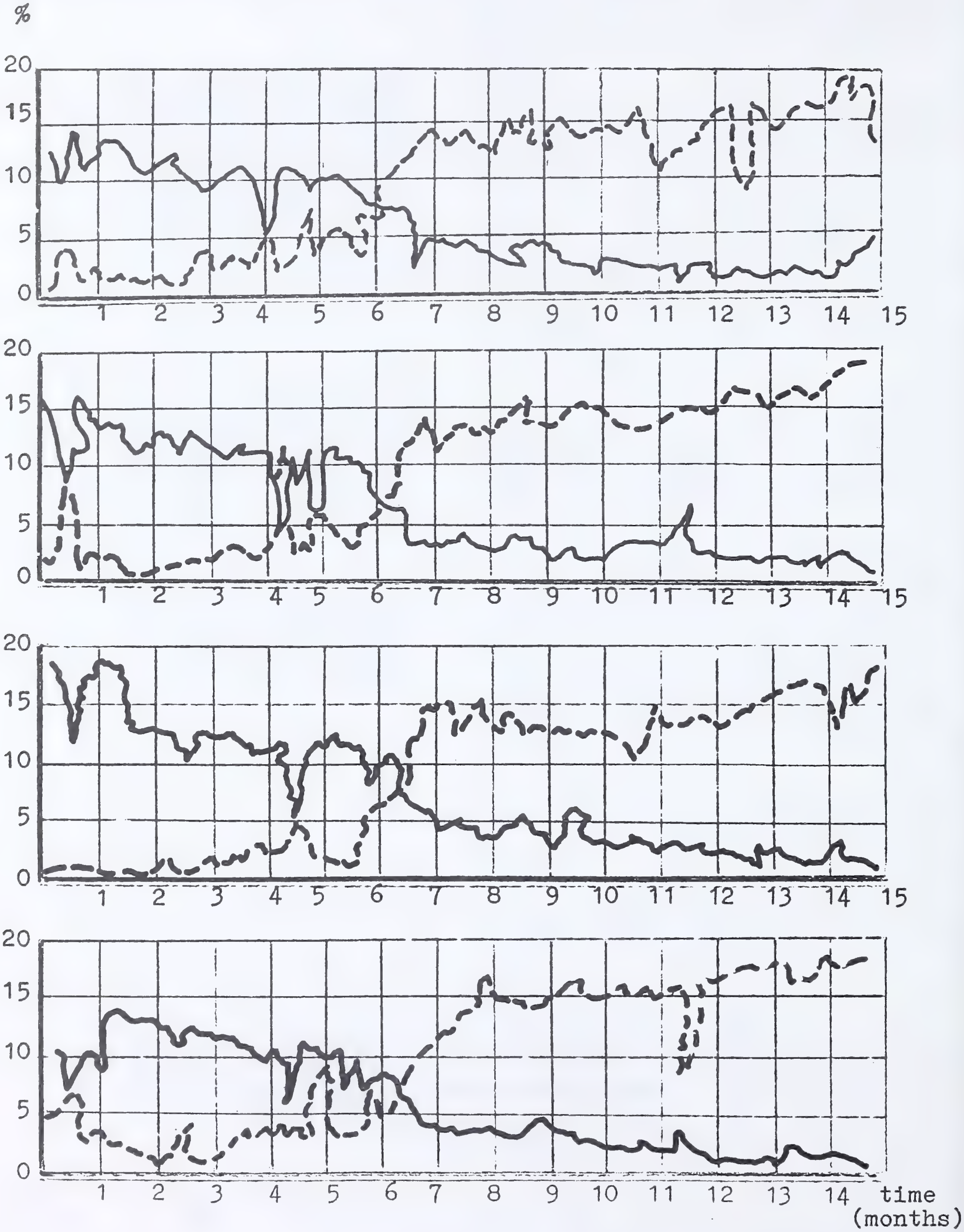


Figure 3. *Changes in oxygen and carbon dioxide content in the produced gas; solid line, carbon dioxide, broken line, oxygen, Zybza Field*

observed in the Borovskoye and Usinskoye oilfields while initiating the in situ combustion process.

- Laboratory and field research works on *in situ* combustion in micro- and macroporous reservoirs are being continued.

RESULTS OF THERMAL BED STIMULATION IN CARBONATE RESERVOIRS BY STEAM OR HIGH TEMPERATURE WATER

High viscosity oil recovery from carbonate reservoirs was carried out for the first time in the USSR in the Zybza oilfield in 1965.

At first, cyclic steaming of wells gave good response in this field. The wells that had not produced before gave high oil production rate (from 3–5 to 30 tons per day) after steaming.
Marginal producers gave similar results.

The first three to four treatments gave the best response and accounted for 75% of the additional oil. The next five to seven cyclic steamings gave a worse response about 5–6% of the ultimate oil recovery per treatment.

High productive life of the wells lasted from 6 to 12 months.

Steam/oil ratio averaged 3–3.5 tons/ton.

Figure 4 illustrates ultimate additional oil recovery as a function of the number of cyclic steamings and steam consumption.

As expected, repeated well steamings were less effective becse the amount of oil in the bottomhole zone declined. Subsequent cyclic steamings (after cycles 5–7) had a poor response. It was determined that injection of steam into carbonate reservoirs particularly after cycles 4–5, resulted in a heat-carrier breakthrough to the other producers, displacement of formation oil and a short term increase of oil production rate of wells (Figure 5). It led to the idea of a new steam drive technology named block cycling steaming.

Heat carrier transfer through high permeability natural channels for heating oil-saturated low-permeability rocks is the main physical concept of the technology. This method differs from oil frontal drive with heat carrier in clastic reservoirs in the fact that:

- Heat carrier moves mainly through high permeability channels of the macroporous reservoir and heats oil in the adjacent low permeability bed;
- Heat carrier moves in the predetermined direction; and
- The process is practiced in two stages:
  - the first stage is characterized by the heat carrier delivery into a macroporous reservoir that results in the heating of the nearest microporous oil saturated reservoir;
  - at the second stage after stopping heat carrier delivery the macroporous reservoir is filled with oil due to the capillary imbibition, viscosity breaking, thermal expansion and higher pressure in microporous reservoir as well as the energy of oil dissolved gas.

Thus at the first stage of the technological process the high permeability channels provide the heat carrier delivery and at the second stage they serve as a pathway for oil and fluids to the producers.

Figure 6 is a schematic diagram of block cyclic steaming. The process consists of the following:

- Heat carrier delivery is performed through two parallel rows of wells in the direction of the producers situated between the rows.
- Heat carrier movement in the given direction is controlled by the adjustment of fluid recovery from the producing wells and steam flow rate into the injection wells when the delineation producers of the plot area are shut down.
- Thermodynamic survey without fluid withdrawal for the whole period of the process is made in the delineation wells of the area.
- The heat carrier movement direction is changed by well shifting when the injectors function as producers and vice versa.

According to the given technique the block cyclic steaming process was first practiced in the Zybza oilfield (depth of the bed occurrence 700–800 m) and then used in the Usinskoye oilfield with a modified technique.

The main oil production results for the mentioned fields are given in Figures 7 and 8.

The Usinskoye oilfield is represented by an oil reservoir of great thickness and exceeds 200 meters. The pool is conventionally divided into three parts and occurs at a depth of 1400–1500 meters. Pilot injection of high temperature water and steam showed that the formations are represented by macro- and microporous reservoirs both vertically and horizontally. It was revealed that continuous steam injection into the formation leads to steam condensate breakthrough into the producers and the reduction of the process response. So taking into consideration the experience of the Zybza oilfield a new modified technology of thermal bed stimulation (thermal cyclic process, *i.e.*, interrupted steam injection) was practiced in the Usinskoye oilfield. This technology is energy saving because steam-oil ratio is within standard limits and doesn't exceed 2 tons/ton (Figure 8).

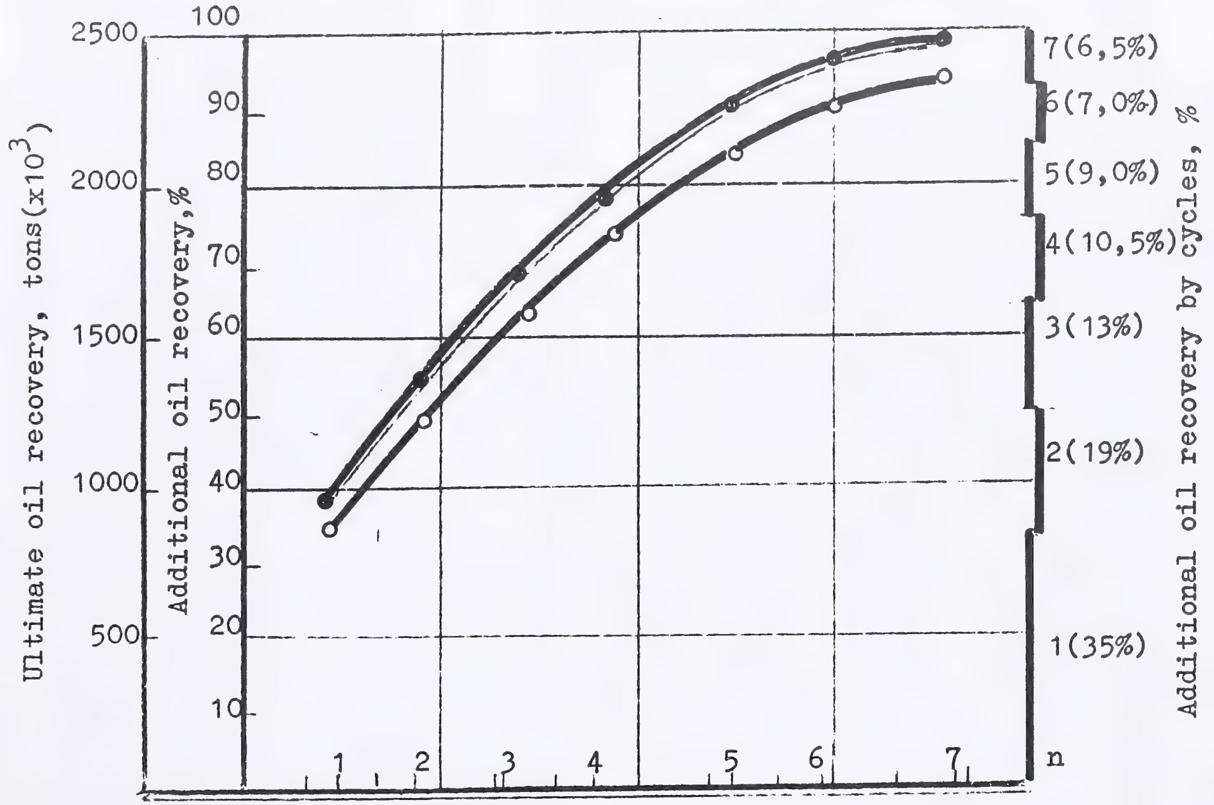


Figure 4. *Ultimate additional oil recovery versus the number of cyclic steamings and steam consumption;* ●—● *ultimate oil recovery (laboratory data);* ○═○ *ultimate oil recovery (field data); n – the number of cycles*

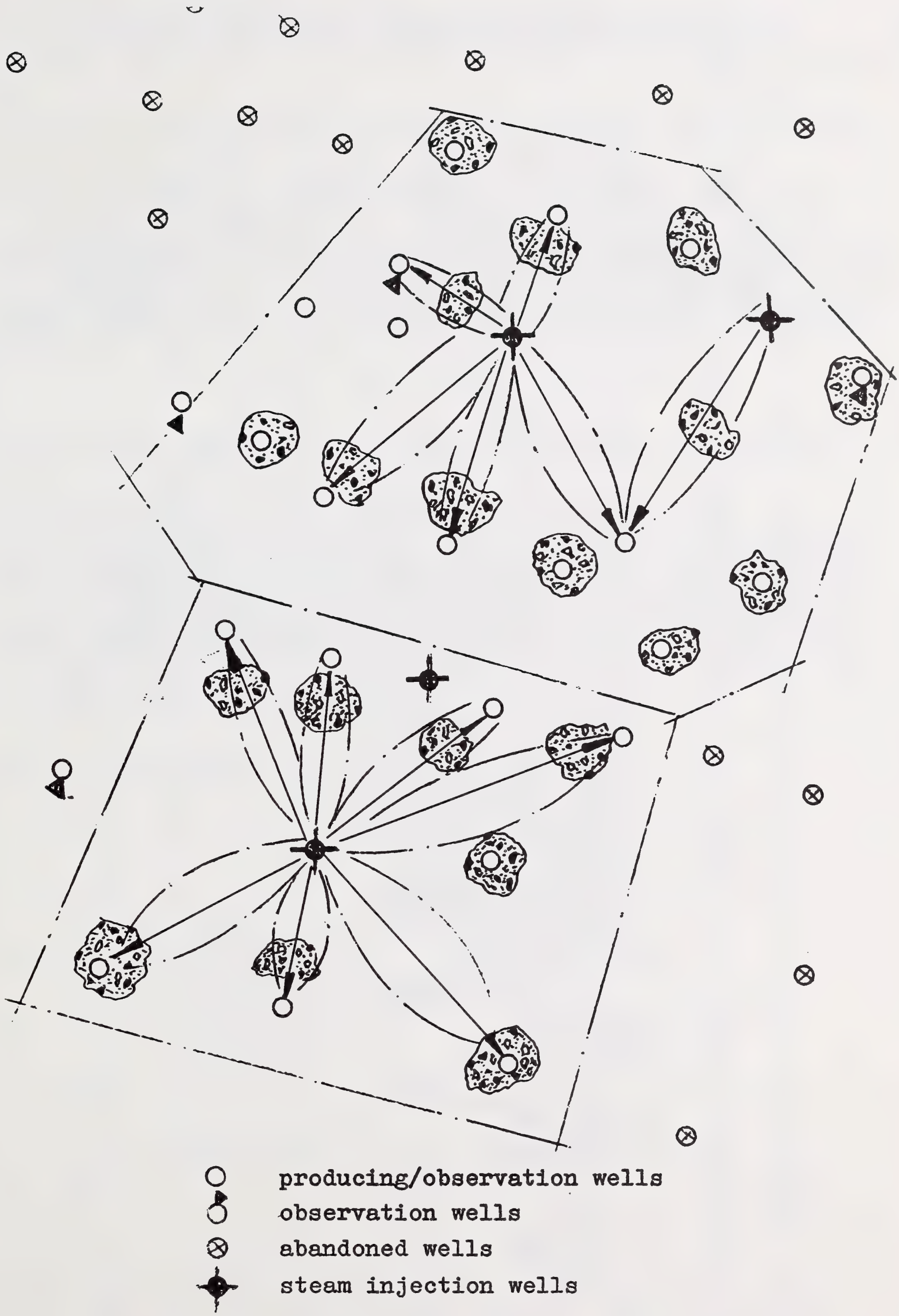


Figure 5. *Heat carrier breakthrough after cyclic steam stimulation*

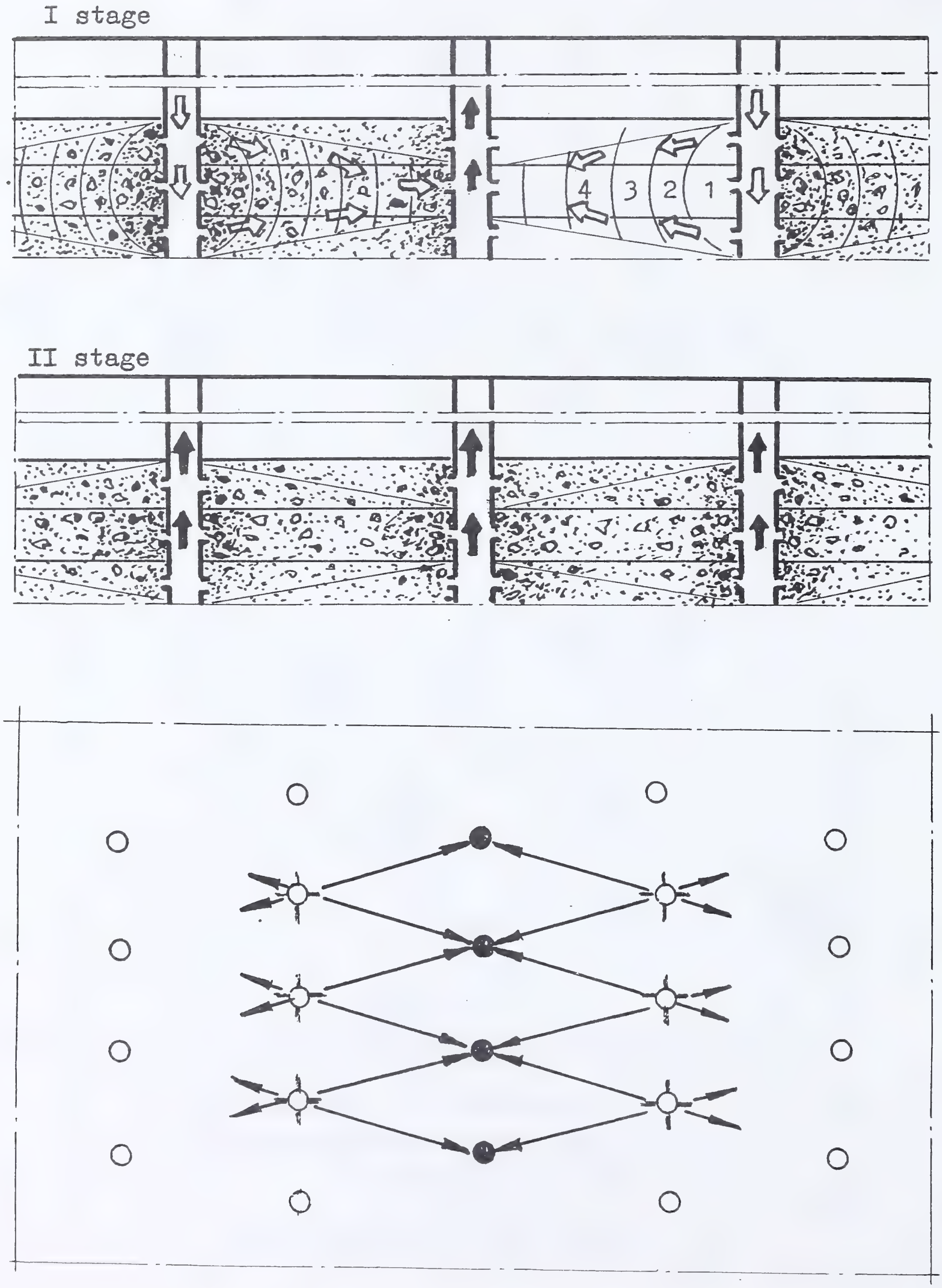


Figure 6. *Block cyclic steaming; 1. steam zone; 2. steam-condensate zone; 3. hot fluid zone; 4. oil slug;⇐ steam; ← oil*

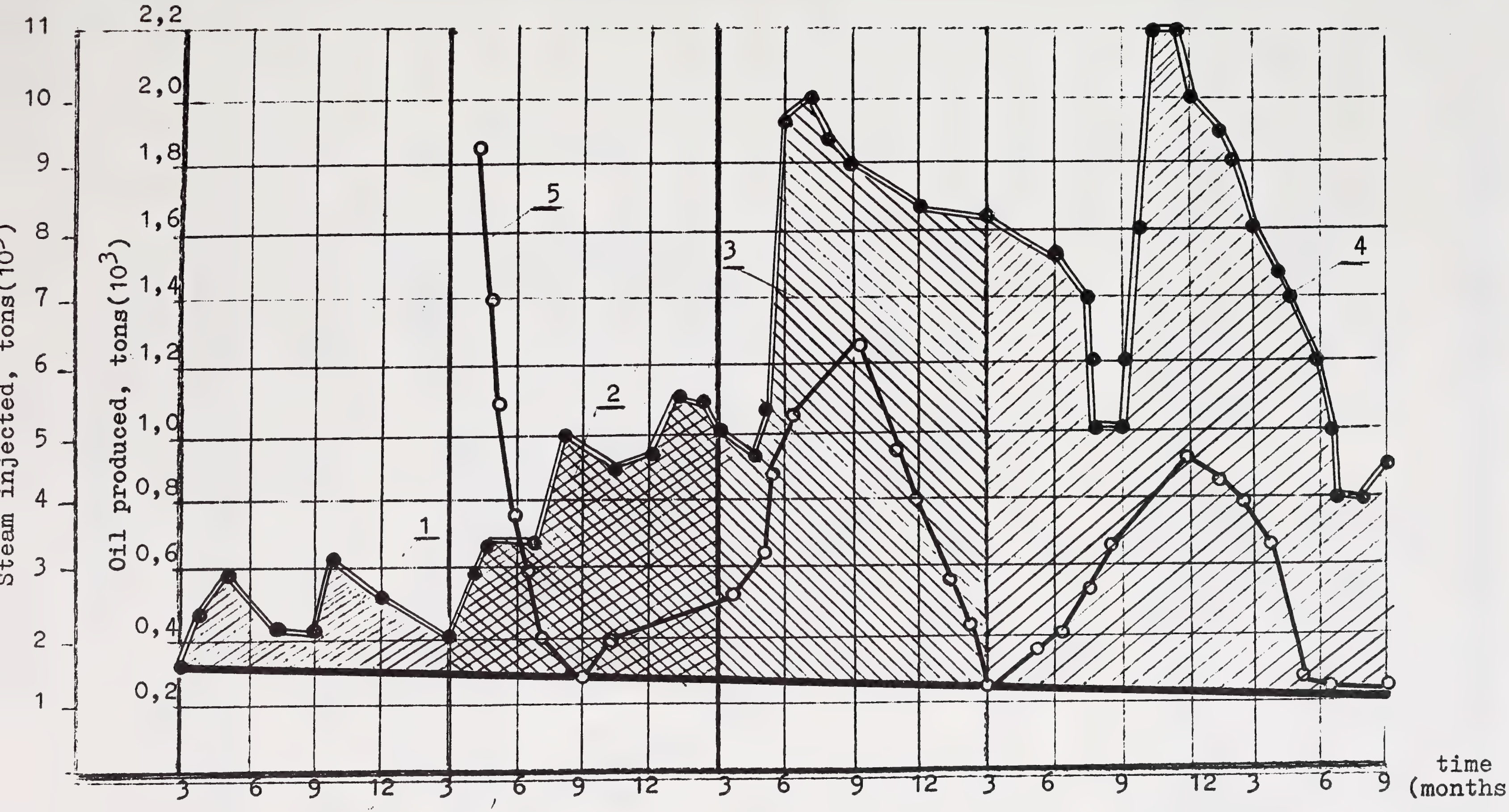


Figure 7. *Oil production in the Zybza oil field; 1. oil produced by cylic steam stimulation of the wells; 2, 3, 4. oil produced by block cyclic steaming; 5. steam-oil ratio*

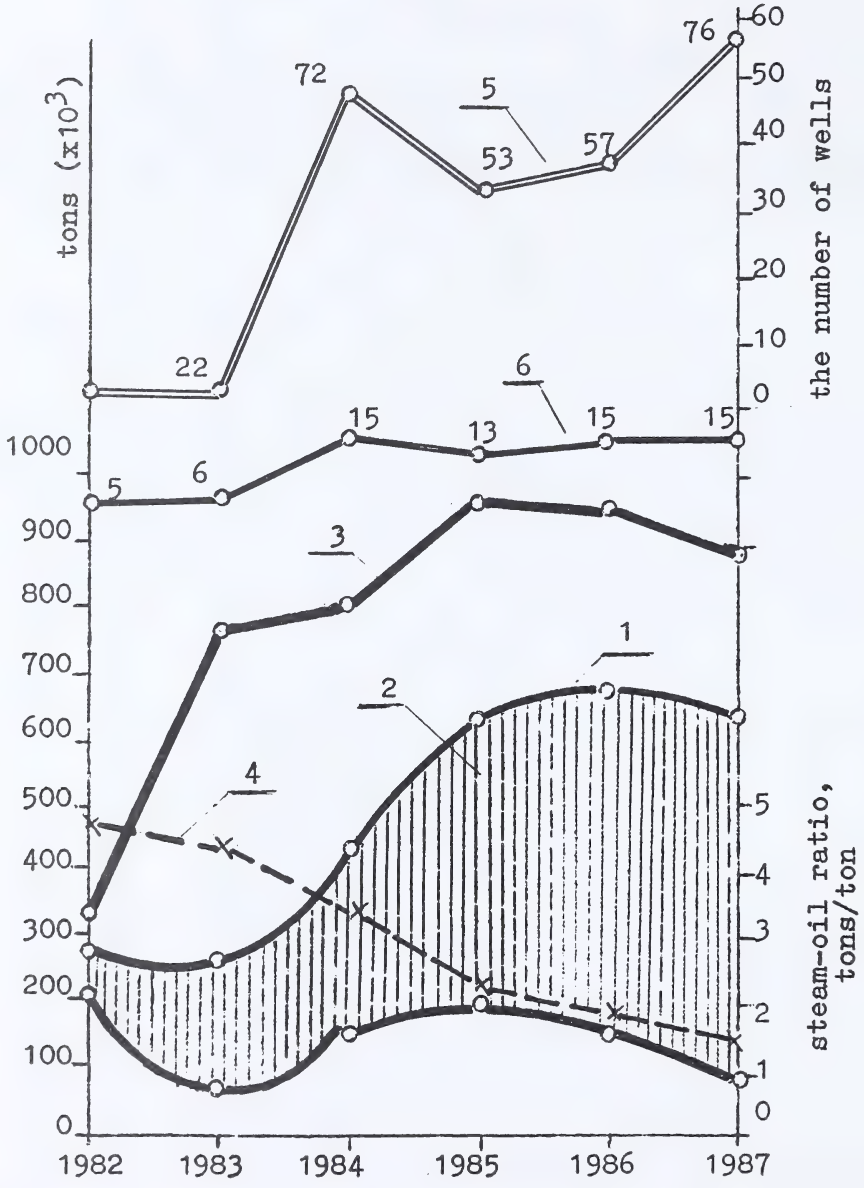


Figure 8. *Oil production in the Usinskoye oil field; 1. annual oil production; 2. additional oil produced by the method; 3. annual volume of steam injected; 4. steam-oil ratio; 5. the number of producing wells; 6. the number of injection wells*

SUMMARY

- Cyclic steam stimulation of wells is recommended for high viscosity oil recovery from carbonate micro- and macroporous reservoirs at the first stage.
- Pattern cyclic steam stimulation is recommended for heating and displacement of oil from microporous to macroporous reservoirs at the second stage.
- At the third stage, after the oil displacement from microporous to macroporous reservoirs, further advance of the oil through the formation can be assisted by cold or hot water and other hot agents. It should be noted that these hot agents should be considered as ones that provide partial recuperation of heat on the one hand and on the other hand they influence hydrodynamically the formation and assist oil advance through high permeability channels to the producing wells.
- Pattern of wells both local and in rows should provide feasibility of any technological process.

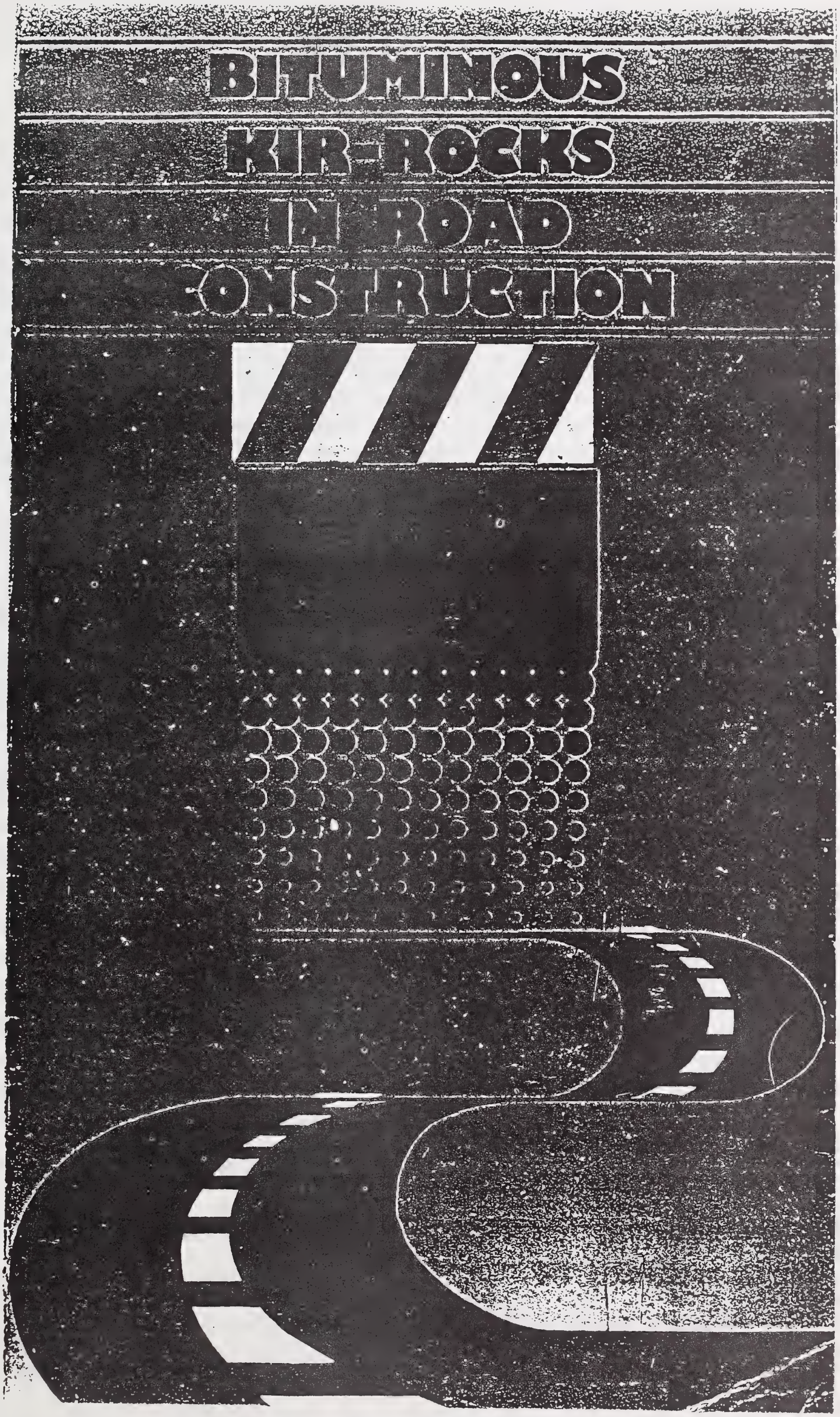
REFERENCE

- Baybakov, N.K. and A.R. Garushev, 1988, Thermal methods for oil field development, 3rd edition revised and enlarged: Moscow, Nedra.

APPENDIX 6

Kazakhstan - Alma-Ata

1. Brochure on production of "Kiree" by Dortehknika.
2. Paper — "Accumulations of Solid Bitumens and High Viscosity Oils in the Southeastern Part of the Caspian Sea".



BITUMINOUS KIR-ROCKS IN ROAD CONSTRUCTION

BITUMENIFEROUS ROCKS — KIRS IN HIGHWAY ENGINEERING

The kirs of western Kazahkstan have been investigated and used in practice by the Kazahk SSR Motor Road Ministry since 1980. Several departments of the Ministry have develped technology of kirs quarrying, transportation, storage, processing as well as using the kirs in their natural form without native asphalt isolation when preparing mixes for pavements.

The structure peculiarities of kirs and their various propertions make the standard technology of asphaltic concrete mix preparation inapplicable. For this reason new non-standard production processes and equipment for preparation and conveying kirs to the standard mixing plants have been developed by the research-and-production association «Dortehknika». The mean operating capacity of the additionally-equipped asphaltic concrete works is 60 t/h. The new technology of asphaltic concrete mix preparation with kirs used makes it possible to exclude commercial asphalt and to reduce consumption of sand by 30—50% and of mineral powder by 10%. The profits make up 5 thous- and roubles per 1 kilometer. The «Dortehknika» and the VNIIStroydormash have designed a drum mixing plant for preparing asphaltic concrete mixes based on bitumeniferous rocks. The application of these drum mixing plants gives the following advantages:

— the quantity of process equipment is decreased;

— the process energy capacity is decreased by 2,5 times;

— the dust emission to atmosphere is decreased by 10—15 times;

— the equipment control and maintenance are simplified;

— the provision of the material «soft» heating by removing their direct contact with the burner open flame.

The kirs of Kazakhstan contain low-viscous asphalts. To improve their properties various polymers can be successfully added. Developed by the «Dortehknika» is a technology of changing the native asphalts in kirs by adding a polymer combining with a high strength of plastic and flexibility of elastomers.

In addition the «Dortehknika» has developed the following technologies of:

— the construction of kir-based «black» pavements by the method of mixing on the road;

— the kir-based hot, warm, and cold asphaltic concrete mix production;

— the kir- and lime-based hydrophobic and activated mineral powder production.

The design and estimate documents have been worked out for the process lines of preparation and conveying kirs to the serial asphalt mixing plants D-597, D-508-2, D-645-2, D-645-3, D-117-2E «Teltomat» and for the drum asphalt mixing plants of capacity 25—30 t/h.

The «Dortehknika» offers the services of «know-how» and «engineering» to the enterprises and firms intrested in the following:

— the provision with standard-technical documents and recommendations on the practical use of bitumeniferous rocks,

— the investigation of proportions and properties of bitumeniferous rocks, local (available) mineral materials and selection of black macadam or asphaltic concrete mixes for beds and pavements.

— the elaboration of standard-technical documents, recommendations and designs for quarrying, transportation and storage of kirs:, production of mixes based on bitumeniferous rocks and using them in pavement construction (taking into consideration the local conditions),

— the elaboration of technical grounds for design and estimate documents and non-standard equipment of the process lines for preparation and conveying the bitumeniferous rocks to serial mixing plants,

— the contract supervision, adjustment and alignment of the lines of conveying bitumeniferous rocks,

— the technical assistance in adjusting the mix production process, in pavement construction and in quality control,

— the manufacture and delivery of the non-standard laboratory equipment, consultations on laboratory service.

Our adress: Alma-Ata, 9 Emtzova st., NPO
«Dortehknika», 480061,
tel. 412431

TECHNIQUES AND FACILITIES FOR COMPLEX PROCESSING OF BITUMINOUS ROCKS

One of the factors restraining the rate of the construction of automobile roads is a deficit in industrially-prepared paving petroleum asphalts. In this connection, highly promising for the road construction is the use of bituminous rocks which are loose rocks, mainly fine sands impregnated with natural bitumens of different viscosities.

Cold, warm and hot asphaltic-concrete mixes are made with bituminous rocks for application in the construction of auto-road bases, base and surface courses. However, a specific structure of bituminous rocks does not permit to use standard techniques for the processing of asphalt concretes and requires the development of novel non--standard processes and equipment.

There are asphaltic-concrete mixing works in Kazakhstan, where bituminous-rock asphaltic concrete is mixed in standard asphalt mixing plants equipped with additional lines for the preparation and feed of the bituminous rocks. The average output of the plants is 60 t/h. The use of industrially-prepared asphalts is fully eliminated, the consumption of sand is reduced by 30-35% and of mineral filler by 10%.

The profit makes up 5 thous.roubles per 1 km.

The technique for the processing of ground bituminous-rock concrete (kir and crushed-stone mixes) is distinguished for the possibility of the bituminous rock processing at low positive and negative temperatures and guarantees a long-term storage of such concrete mixes.

The use of kir and crushed-stone mixes for making asphaltic concrete makes it possible to improve the performance reliability and to increase the asphaltic concrete mixer output, to eliminate the line for the preparation, feed and batching of bituminous rocks owing to the mix feed by the crushed-stone feed line; it also allows to improve the working conditions, to decrease greatly the ejection of dust particles owing to the dust suppression by the organic fraction of the bituminous rock.

The road bases built of kir and crushed-stone mixes, as opposed to those constructed of fractional crushed stone or crushed-stone mixes of the optional proportions by the standard technique, are characterized by high physical and mechanical properties, by a higher modulus of elasticity, which makes it possible to reduce the road base thickness.

The profit makes up 1.3 thous.roubles per 1,000 tons of mix.

The asphaltic concrete mixing plants, employing drum mixers, for the processing of asphaltic-concrete mixes with bituminous rock offer a number of advantages: low specific electric power and fuel consumption, small specific quantuty of metal per equipment, absence of complex clearing facilities, simplicity of assembly.

The annual profit is 38 thous.roubles.

The application of bituminous rocks containing high percentage of the organic fraction does not cause any serious difficulties, but when the natural bitumen content is low in the rock various constituents are required to be added in the concrete mix.

The asphaltic-concrete mixes with bituminous rocks low in natural bitumen and with the addition of hydrocarbon constituents or low-molecular polyethylene are processed in standard mixers equipped with lines for the preparation and feed of the bituminous rocks, as well as with an additional line for the low-molecular polyethylene feed in the latter case.

The obtained asphaltic-concrete mixes exhibit high physical and mechanical properties.

The technique for paving the roads with these asphaltic-concrete mixes does not differ from the conventional technique.

The use of bituminous rocks low in natural bitumen considerably reduces the construction cost.

Saving in materials per 1,000 tons of mix is equal to 35 tons of industrially-prepared asphalt and 320 cu.m. pf sand.

The profit is 3-5 thous.roubles per 1 km.

Developed by the "Dortekhnika" Research and Production Amalgamation under the Kazakh SSR Ministry of Automobile Roads.

ПМЛ МАД КазССР. Зак 5595-400

ACCUMULATIONS OF SOLID BITUMENS AND HIGH-VISCOSITY OILS IN THE SOUTHEASTERN PART OF THE CASPIAN BASIN

V. V. Lipatova, E. A. Svetlakova, M. S. Trokhimenko
(VNIGNI, ZapKazGeologiya)

In the resolutions of the XXV session of the Communist Party of the Soviet Union, the Caspian basin was named among the regions which should provide the main increase in oil and gas. Here three complexes are regionally oil- and gas-bearing: the subsalt (pre-Kungurian), Upper Permian-Triassic and Jurassic-Lower Cretaceous. The main prospects in recent times are related to the subsalt deposits, and the Upper Permian-Triassic complex is second in predictive estimates. The total potential reserves of the Jurassic-Cretaceous complex are estimated today as being low, although until recently these deposits were the main object of oil production in the oldest oil-producing area of the country -- the South Emba. However, recently the backlog of promising structures in this complex has already been largely exhausted, new targets of investigation have appeared, and therefore the deposits most accessible for development came to be assigned to the category of secondary. Nevertheless the potential possibilities of the Jurassic-Cretaceous complex have been far from completely investigated. In the east and southeast of the Caspian basin, considerable accumulations of hydrocarbons have been found, confined to surface beds (kirs) or not very deep (up to 200-300 m), under conditions of poor fluid retention. The oils have lost their benzine component and have become viscous and tarry, which makes it difficult to recover them via wells.

The first reports of outcrops of kirs came at the end of the last century (kirs in the Dzhamanagach area, 1886). Later, kir-ized sands were found on the Ittasay. IN 1915 a well was drilled to 220 m on this structure, penetrating 14 layers of kir-ized sands. Outcrops of kir-ized sandstones were described on the Kursay, Sorkuduk and Taskemir. Surface oil shows were observed in a detailed survey on the Keykebas. Numerous bitumen deposits were found in the area of the South Emba (fig. 1). In the Karakhobda area kir-ized rocks were penetrated by wells in the 3.0-12.0 m interval. Kir-ized rocks were also reported in the Aktyubinsk Cis-Ural area, in the Aleksandrovsk and Petropavlovsk folds. Altogether more than a hundred surface outcrops of bitumens were counted in the territory in question.

One of the objects of the suprasalt complex of the Caspian basin containing deposits of high-viscosity oil at shallow depth is the Kumsay field, where accumulations of high-viscosity and tarry oil are concentrated in the Middle Jurassic clastic rocks (I. B. Dal'yan et al., 1972). The low recovery made well exploitation unprofitable in this field and was the reason why these reserves were assigned to the category of unworkable. However, experience with industrial and experimental development of oil pools by the mining method (Pechelbronn and Gabian fields in France, Monterado and Wietze in Germany, Santa Monteoru in Romania, Venango and others in the USA, Higashiyama in Japan, Shubanov and Yarega in the USSR, etc.) raises the question of the need to seek a method of profitable exploitation of this field.

To exploit the Kumsay field, apparently, it would be useful to use the experience of working the Yarega field in the Timan-Pechora oil and gas province (A. A. Khanin, 1973, and others). These two deposits are identical in their main parameters — size of pool; lithologic particulars of the rocks containing the oil, their porosity, permeability, density; type; composition of the oils, their paraffin content, conditions of occurrence; their content of sulfur, silica-gel resins, asphaltenes; the gas factor; and absence of benzine and a gas cap (table, figs. 2, 3). Such differences as the type of pool and age of the country rocks are unimportant in this case, as they hardly affect

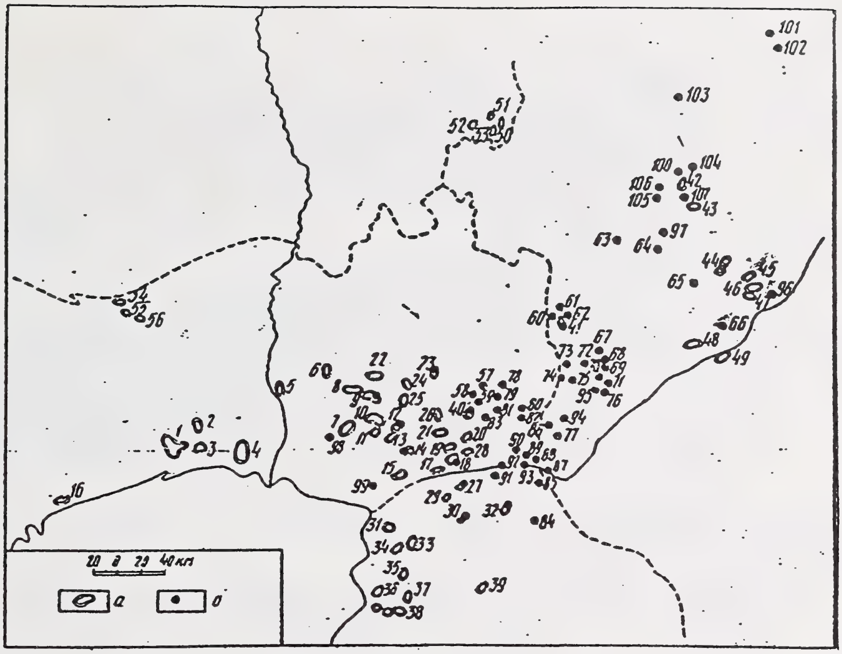


Fig. 1. Scheme of the spatial distribution of oil fields, pools and natural outcrops of bitumens in the southeastern part of the Caspian basin:

a - oil fields and pools: 1 - Zhanatalap; 2 - Gran'; 3 - Martyshi; 4 - Kamyshitovyy; 5 - Baklanyy; 6 - Karatal; 7 - Iskine; 8 - Tanatar; 9 - Dossor; 10 - Tyulegen'; 11 - Baychunas; 12 - Bisbulyuk; 13 - Tentyaksor; 14 - Akatkul'; 15 - Korsak; 16 - Oktyabr'skaya; 17 - Ayrankul'; 18 - Kzylkala; 19 - Antykul'; 20 - Kamyskul'; 21 - Narmundunak; 22 - Zhengel'dy; 23 - Zholdybay; 24 - Makat; 25 - Sagiz; 26 - Koshkar; 27 - Kulsary; 28 - Dyuseke; 29 - Koschagyl; 30 - Tyulyus; 31 - West Teren'uzyuk; 32 - Munayli; 33 - Karaton; 34 - Tazhigali; 35 - Karaarna; 36 - Morskoy; 37 - Aktyube; 38 - Prorva; 39 - Burankul'; 40 - Bekbeke; 41 - Kopa; 42 - Dzhaksymay; 43 - Shubarkuduk; 44 - Karaganda; 45 - Kumsay; 46 - Kenkiyak; 47 - Kokzhide; 48 - Akzhar; 49 - Karatyube; 50 - Chingiz; 51 - Telsu; 52 - Beket; 53 - Kubasay; 54 - Bolganmola; 55 - Auketaychagul; 56 - Karagayskaya; b -natural bitumen outcrops: 9 - Dossor; 12 - Bisbulyuk; 14 - Akatkul'; 18 - Kzylkala; 23 - Zholdybay; 27 - Kulsary; 30 - Tyulyus; 32 - Munayli; 40 - Bekbeke; 41 - Kopa; 44 - Karaganda; 57 - Dzhalgaz; 58 - Kutartas; 59 - Alambay; 60 - Zhdalya; 61 - Munaylisay; 62 - Levite; 63 - Sorkuduk; 64 - Karaulkel'sy; 65 - Ittassay; 66 - Kursay; 67 - Saryk; 68 - Murzaadyr; 69 - Dongeleksor; 70 - Koskul'; 71 - Aktakyr; 72 - Kzyldzhar; 73 - Kiyaktysay; 74 - Uzunkul'; 75 - Zhdamankoblandy; 76 - Tersakkan; 77 - Alashakazgan; 78 - Togusenushak; 79 - Dzhilankaban; 80 - Kirasay; 81 - Akchiy; 82 - Karamurat; 83 - Imankara; 84 - Ul'kentyube; 85 - Isekdzhal; 86 - Chubantam; 87 - Uyaly; 88 - Araltyube; 89 - Bakachi; 90 - Dzhusalysay; 91 - Takyrbulak; 92 - Kul'dzhan; 93 - Kaskyrbulak; 94 - Shilisay; 95 - Ak-cheka (Kayraktykyl'); 96 - Mortuk; 97 - Kumbaur; 98 - Abzhel'; 99 - Zhdarchik; 100 - Dzhamanagach; 101 - Petropavlovskaya; 102 - Aleksandrovskaya; 103 - Karakhobda; 104 - Kalmyk-Karagan; 105 - Alaty-Karasu; 106 - Taskemir; 107 - Keykebas.

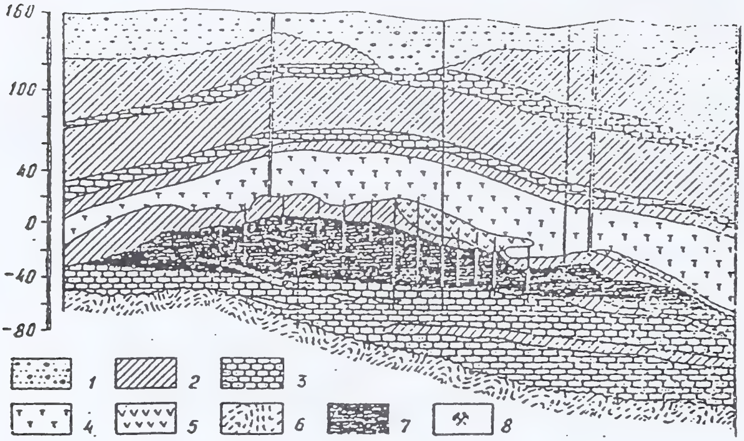


Fig. 2. The Yarega oil field (Timan-Pechora oil province). Pool in formation III (Middle Devonian).

1 - Quaternary deposits; *2* - argillaceous rocks; *3* - sandstones; *4* - tuffites; *5* - diabases; *6* - metamorphic schists; *7* - oil, *8* - mine workings.

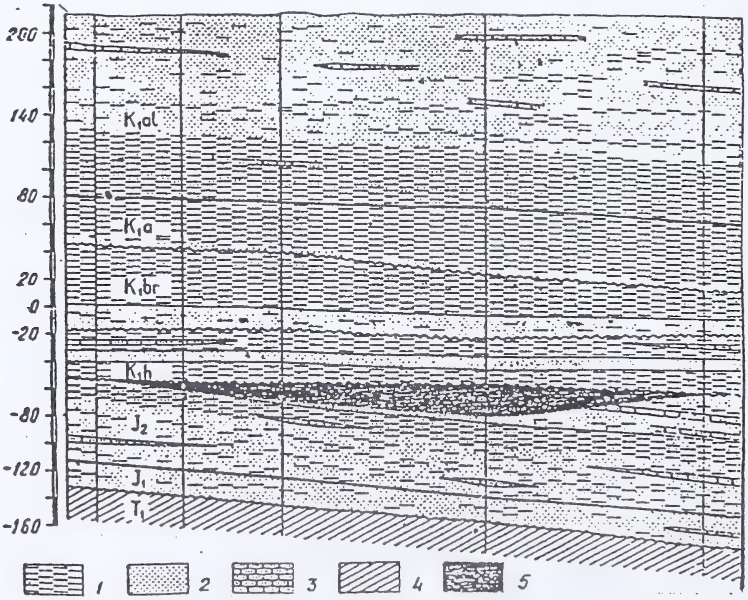


Fig. 3. The Kumsay oil field (Caspian basin). Pool in Middle Jurassic deposits.

1 - clays; *2* - sands; *3* - sandstones; *4* - sandy-clayey deposits of the Lower Triassic; *5* - oil.

Parameters	Fields	
	Yarega	Kumsay
Depth of pool, m	150-220	230-330
Type of pool	Anticlinal	Lithologic
Age of rocks containing the oil	Middle Devonian	Middle Jurassic
Lithology of producing horizons	Sandstones, sands, clays, claystones, conglomerates	Sandstones, sands, claystones, siltstones, clays
Total thickness of producing horizons, m	30	5-16
Level of oil-bearing capability, m	40-45	55
Regime of operation of oil-bearing formations	Dissolved gas & gravitational	Dissolved gas & gravitational
Dips of formations, in degrees	Up to 5	Up to 12
Open porosity of rocks of producing horizon, %	12-15	30-38
Commonest perm porosity of rocks of producing horizon, mD	1500-2000	220-2200
Formation pressure, kg/cm^2	15	23-26
Formation temperature, °C	6	13-23
Gas cap	None	None
Gas factor, m^3/m^3	About 6	Up to 2
Type of oil (on distillate part up to 300°C)	Naphthenic	Naphthenic
Yield of oil in wells, t/day	1.5	0.7-1.0
Kinematic viscosity, cCt at 50°C	406	About 400
Density of oil, g/cm^3	0.938-0.947	0.939
Content in oil of (%):		
sulfuric acid resins	50	31-50
silica-gel resins	17-29.4	19.4
asphaltenes	3.68-4.8	3.38
paraffins	0.4	0.36
sulfur	1-1.2	0.6-0.7
benzine (fraction boiling up to 200°C)	None	None
Composition of casing-head gas	Chiefly methane	Chiefly methane

the possibility of mining the Kumsay deposit. The deeper occurrence of the oil-bearing formations in the Kumsay field compared to the Yarega does not prevent putting in a shaft, as deeper vertical workings are known (USSR, Romania). Using mining can essentially increase the extent of oil recovery from the formation compared to well development (A. Ya. Krems et al., 1955).

APPENDIX 7

Baku - Azerbaijan

1. Proposal from Roevin Deutschland GmbH concerning a joint venture on the Apsheron Peninsula.

ROEVIN
DEUTSCHLAND (U.K.) LTD

Suite 4,
2, South Street,
Hythe, Southampton.
SO4 6EB. England

16th November 1989

Mr. W. Yorko
Alberta Oil Sands Technology and
Research Authority
500 Highfield Place
10010 - 106 Street
Edmonton, Alberta
T5J 3L8
Canada

DEVELOPMENT OF THE REGIONS OF APSHERONSKI AND SHEMAKHINO - KOBISTANSKI BITUMEN (TAR SANDS) DEPOSITS USSR

Gentlemen:

May we introduce Roevin Deutschland GmbH.

Roevin Deutschland in association with our Joint Enterprise partners the Commercial Union "Aznyeft" have the commercial rights to develop the Regions of Apsheronski and Shemakhino - Kobistanski bitumen [tar sands] deposits. Refer to the enclosed map of the region which shows the location of the bitumen deposits which are covered by our joint enterprise agreement.

Our reason for contacting Alberta Oil Sands Technology and Research Authority, is to inquire into their interest to be involved in this development by means of:
[a] the licensing of their technology. or
[b] on a consultancy basis.
which ever of these approaches the authority adopt or any alternative, we are prepared to meet with you to discuss.

To ensure the success of this project the Joint Enterprise Group [Roevin - Aznyeft] shall invite international companie to form a consortium to exploit this national resource. And to this end we are in meaningful discussions with a number of the major oil companies.

The newly formed consortium shall undertake a feasibility study to confirm the viability of the development and to satisfy, to all principle partners, the acceptable level of return on their investment, together with the assurance that their investment will be protected for the life of the project.

Roevin - Aznyeft shall examine and obtain all licences, permits and other legal documents required for the project, and to pass them through the proper USSR state regulatory institutions.

We are enclosing copies of the bitumen specification, which are the results of a study undertaken by Aznyeft engineering group for the area identified.

Our Mr Cliff Lambert will be in Canada over the Christmas period, he will be pleased to meet with you in Edmonton, January 3rd, 1990 if this meets with your schedule. Could you please confirm this date is convenient.

Yours sincerely,
for Roevin Deutschland GmbH.

Lambert

Clifford E. Lambert.
Group General Manager.

cc: Dr. D. Redford
Mr. J. Yorko

English translation of Shale Oil Certificate

CERTIFICATE

The particular important significance is for the republic to have the utilisation of hydrocarbon raw materials from natural bitumen for obtaining "Synthetic Oil" [wash off the contents of hard oil rock/types of hard oil], and also for construction materials and raw materials for local industry.

Out of all the significant quantities of deposits and accumulatio of natural bitumen, the Kirmaku deposit has been the most and are very valuable compound materials.

The Kirmaku oil fields are situated in the central part of the Apsheronski Peninsular, twelve [12] Kilometers to the North-East of the City of Baku, in the Azerbaijhanian, Soviet of Socialist Republics. The oil fields boarder on the oil industrialised regio of the Balakhani - Sabunchi - Romani to the East, and with the oil industialised region of Binagadi from the West, close to the Kirmaku population point situated about 1.5 to 2.0 kilometers to the South-East of the Balakhani settlement. Further South the industial railway passes by the oil fields and the asphalt - impregnated highway passes South-West.

The Kirmaku deposites are in fact prepared for exploitation.

Bitument reserves along two levels of exploration [+25.00 metres to 0.00 metres and 0.00 metres to -65.00 metres] are confirmed in the quantity of 16.60 million tonnes.

Along the third level of exploration [-95.00 metres to -300.00 metres] the reserves are estimated to be in the quantity of 35.00 million tonnes, i.e. representing arbitrarily hard oils. Altogether the Kirmaku deposits are more than 50.00 million tonnes of bitumen and hard oils.

Area of the beds:	2,766,000.00 Metres Cubed
Oil Saturation thickness	45.80 metres
Degree of Porosity	25.00%
Permeability	0.400 mk/metre squared
Oil saturation of rock	102.880 kg/metre cubed [10.00 to 12.00% by weight]

The refining of the area marked out will be carried out with two phases:

1st level: from the surface to the layer +35 metres.

2nd level: from +35 metres level to - 25 metres level.

The co-efficient for the oil output is taken by GKZ, USSR as 1.00

As a result of the process refining of oil saturated rock with oil content of 10.0 to 11.0% an oil product was obtained with a specific gravity range from 0.905 to 0.914 as a function of the temperature operating conditions of the installation, with the initial boiling point at 125 degrees to 203 degrees.

Distillation Fractions:

? Fractions:	17.0%
Diesel Fuel:	57.0%
Engine Distillates:	18.0%
Residue:	8.0%

Information received as a result of the refining of bitumen sands from Kirmaku. Oil product in the form of broad fractions were recommended for use in the capacity of materials for catalytic cracking with the aim of extracting automabile gasoline and other products from them.

Signed by:__________?____________
'15-09-1988

СПРАВКА

Особое важное значение для республики имеет использование углеводородного сырья природных битумов для получения "синтетической нефти" (отмытые от содержащей породы тяжелые нефти), а также строй-материалов и сырья для местной промышленности.

Месторождение Кирмаку наиболее изученное среди значительного количества месторождений и скоплений природных битумов, представляющих собой ценное комплексное сырье.

Месторождение нефти Кирмаку расположено в центральной части Апшеронского полуострова, в 12 км. на северо-восток от г. Баку Азерб. ССР. Месторождение граничит с востока нефтепромысловым районом Балаханы-Сабунчи-Романы и с запада с нефтепромысловым районом Бинагады. Ближайшим к площади Кирмаку населенным пунктом является, находящееся в 1,5-2,0 км. на юго-восток, селение Балаханы.

Южнее месторождения проходит промысловая железная дорога, юго-западнее площади - асфальтированное шоссе.

Месторождение Кирмаку фактически подготовлено к эксплуатации. Запасы битумов по двум этапам разведки (+25м-0м и 0м-65м) утверждены в количестве 16,6 млн.т. По третьему этапу разведки (-95м-300м) запасы оценены в количестве 35 млн.т. и представлены условно тяжелыми нефтями. Всего на месторождении Кирмаку имеется более 50 млн.т. битумов и тяжелых нефтей.

Площадь залежи - 2766 тыс.кв.м.
нефтенасыщенная мощность - 45,8 м
пористость - 25%
проницаемость - 0,400 мкм^2
нефтенасыщенность пород - 102,88 кг/м^3 (10-12% вес)

Разработку площади намечается произвести двумя очередями:
I этап - от поверхности до отметки +35 м,
II этап - от +35 м до - 25 м
коэффициент нефтеотдачи принят ГКЗ СССР - 1,0

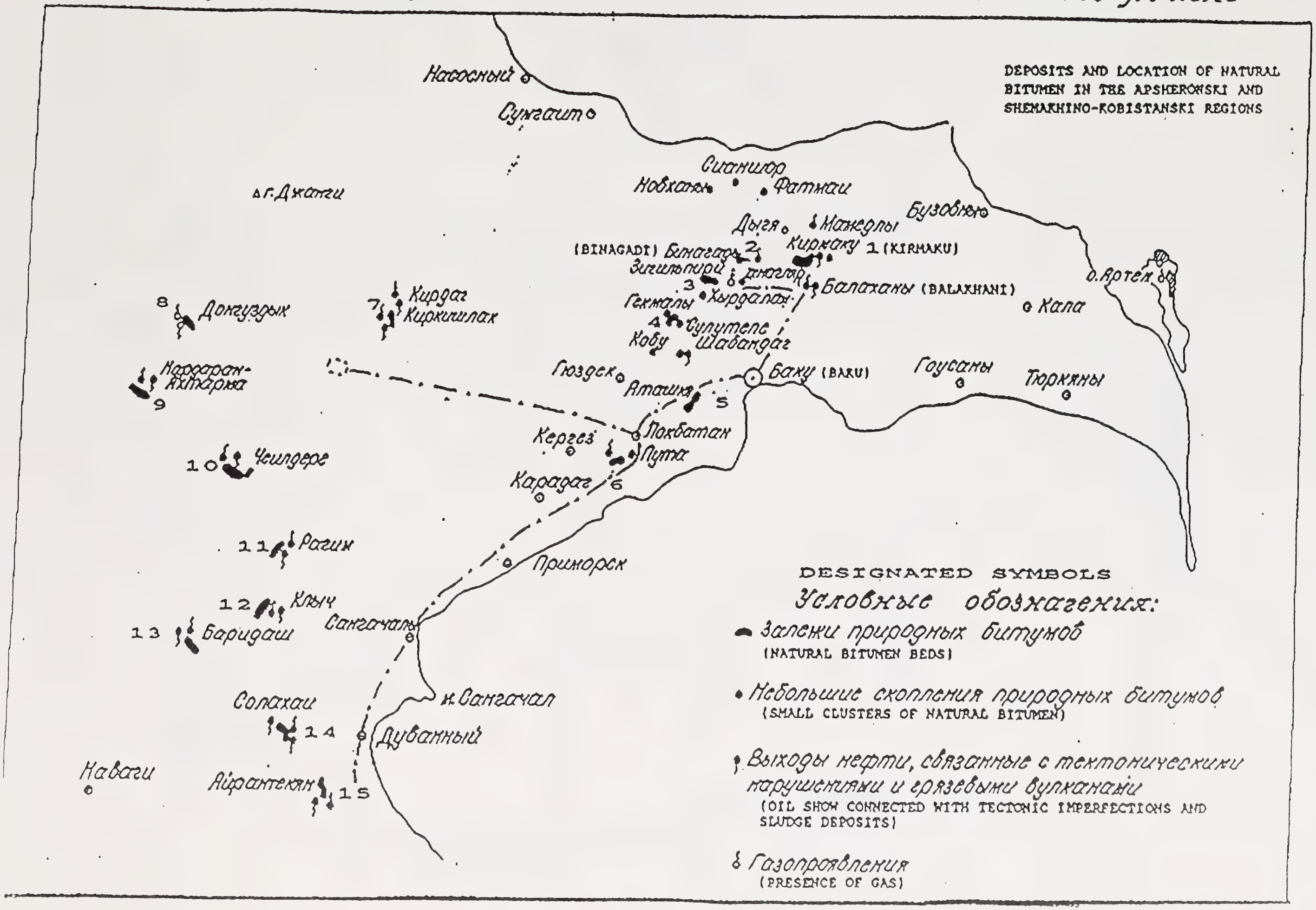
В результате переработки нефтенасыщенных пород с содержанием нефти 10-11% был получен нефтепродукт с уд. весом от 0,905 до 0,914 в зависимости от температурного режима работы установки, с началом кипения от 125° до 208°. Фракционным составом:

- легроиновая фракция - I7%
- дизельное топливо - 57%
- машинный дистиллят -I8%
- остаток - 8%

Полученный в результате переработки битуминозных песков Кирмаку нефтепродукт в виде широкой фракции был рекомендован к использованию в качестве сырья для каталитического крекинга с целью получения из него автомобильного бензина и др.продуктов.

15. 09.88.

есторождения и скопления природных битумов Апшеронского и Шемахино-Кобыстанского районов



DEPOSITS AND LOCATION OF NATURAL BITUMEN IN THE APSHERONSKI AND SHEMAKHINO-KOBISTANSKI REGIONS

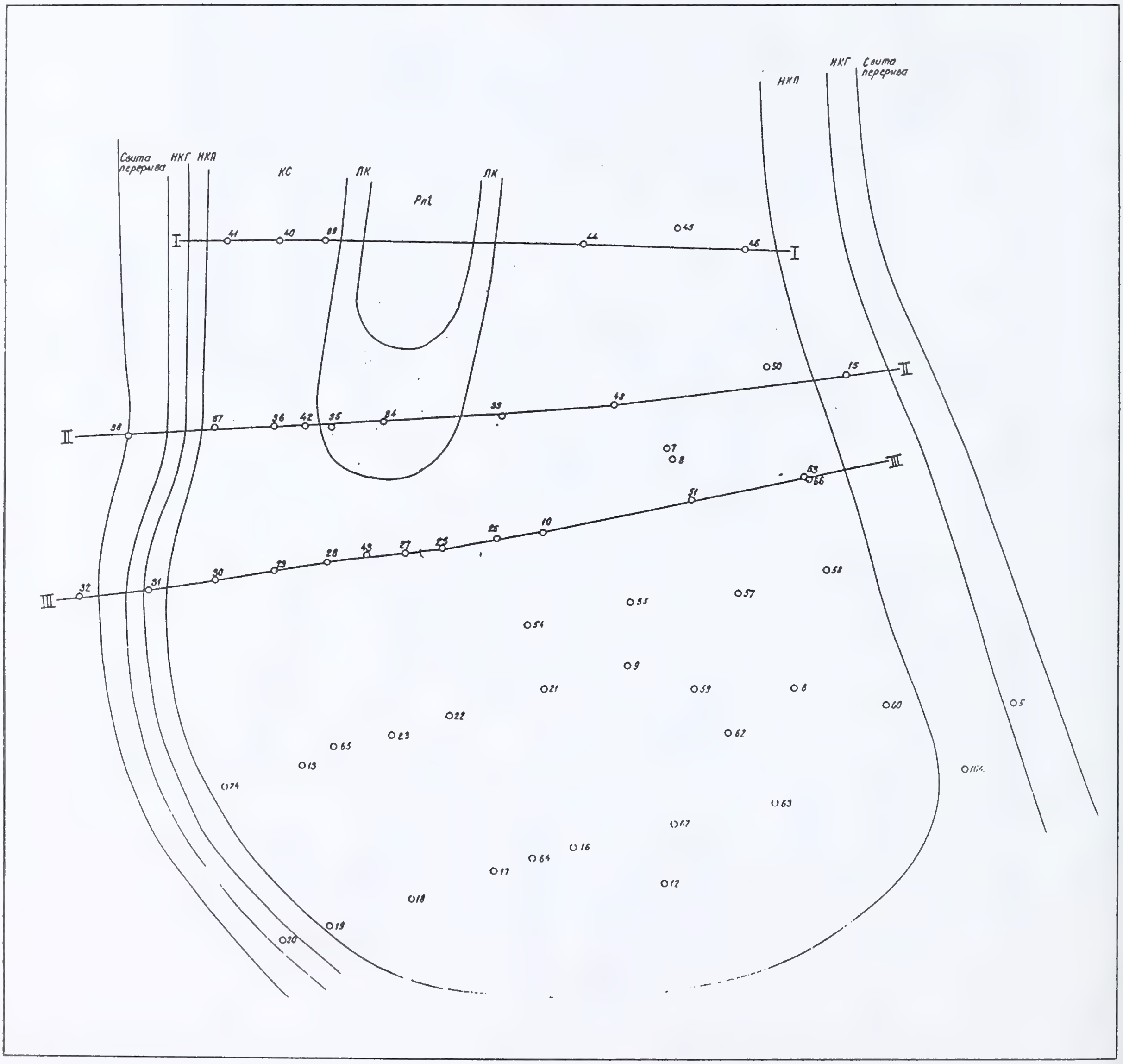
DESIGNATED SYMBOLS

Условные обозначения:

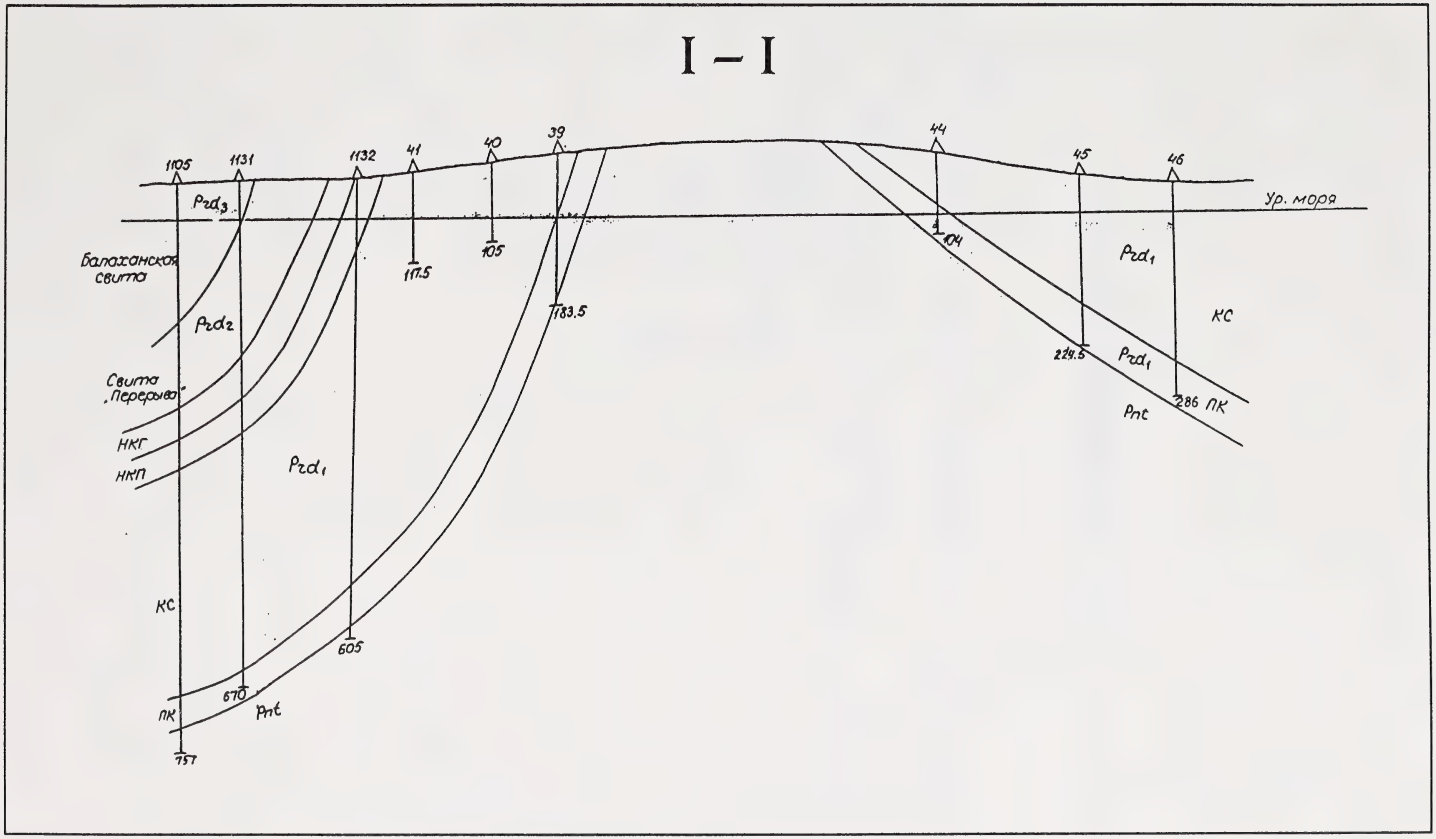
- ▬ Залежи природных битумов (NATURAL BITUMEN BEDS)
- • Небольшие скопления природных битумов (SMALL CLUSTERS OF NATURAL BITUMEN)
- Выходы нефти, связанные с тектоническими нарушениями и грязевыми вулканами (OIL SHOW CONNECTED WITH TECTONIC IMPERFECTIONS AND SLUDGE DEPOSITS)
- Газопроявления (PRESENCE OF GAS)

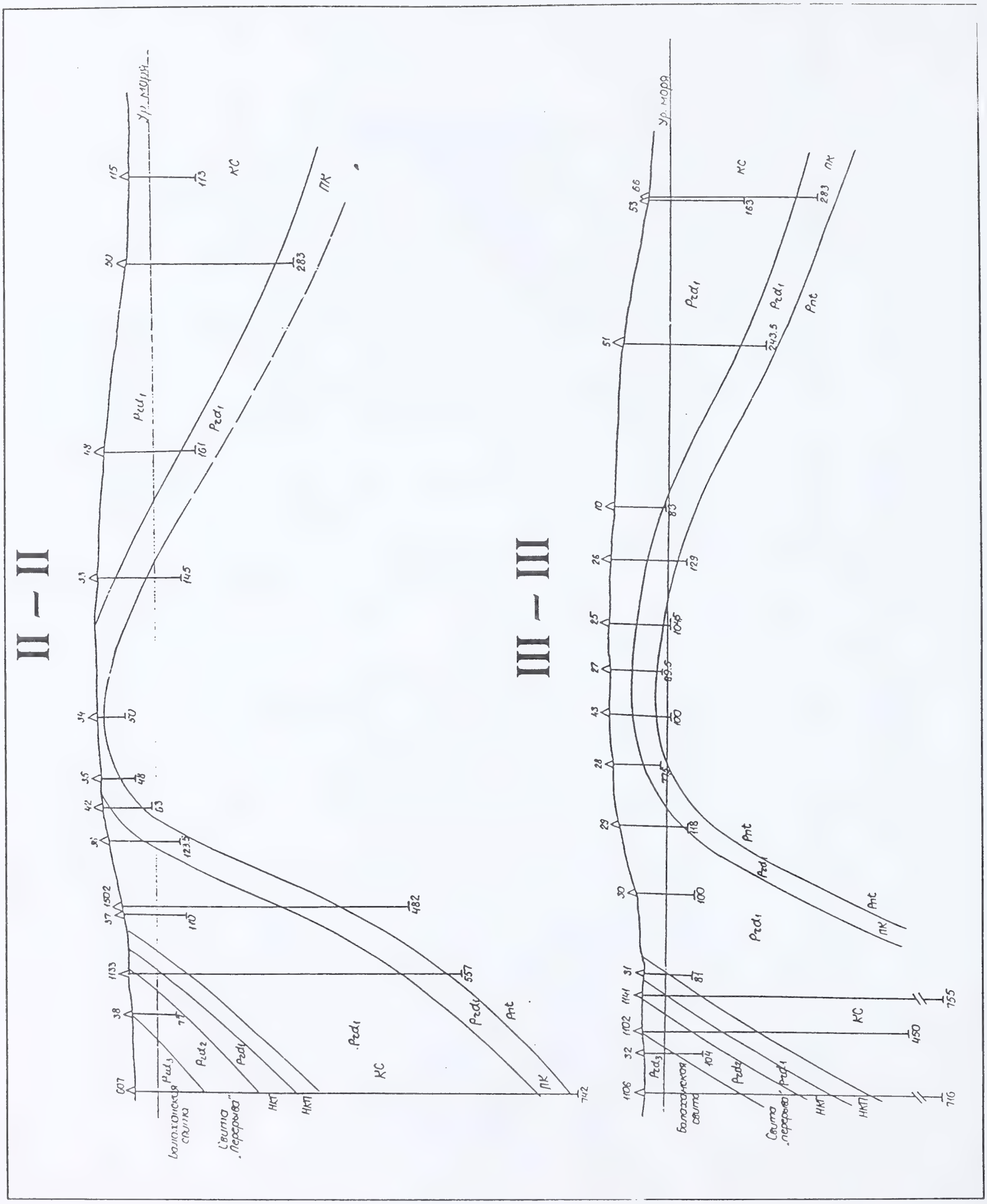
—·—·— OIL PIPELINES (EXISTING)

Kirmaku geological map
Scale 1:500



Kirmaku geological profile
Scale 1:5000




II – II
ур. моря
KC
ПК
Pzd₁
Pzd₂
Pzd₃
Pnt
НКТ
НКП
балаханская свита
Свита „Перерыва"
115
173
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283
18
161
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145
54
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42
63
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123.5
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III – III
ур. моря
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балаханская свита
Свита „Перерыва"
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100
28
77.5
29
118
30
100
31
81
1141
755
1102
450
32
104
1106
716

APPENDIX 8

Miscellaneous

1. Paper — 'Competitive Technologies of Thermal Methods for Heavy Oil Production'.
2. Paper — 'Geological Problems of Natural Bitumen'.
3. Oil Production in the U.S.S.R. to 1986 (International Petroleum Encyclopedia 1987).
4. Soviet Union 'Facts and Figures'.

COMPETITIVE TECHNOLOGIES OF THERMAL METHODS FOR HEAVY OIL PRODUCTION

A. A. Bokserman, *Specialist in thermal techniques for oil field development, All-Union Oil and Gas Scientific Research Institute (VNII), USSR*;
N. L. Rakovsky, and M. F. Putilov, *VNII, USSR*.

Abstract. In the USSR power-saving technologies have been tested and applied for the development of heavy-oil fields, based on a combination of thermal stimulation methods and waterflooding. Such a combined technology is realized by creation and movement of thermal slugs along the reservoir. The change to the combined technology leads to a decrease in the requirement for power-intensive working agents (steam and compressed air) for oil production.

In this connection, the optimization of well pattern and density of well spacing, fluid injection and withdrawal conditions, and sizes of thermal slugs are of great importance. To solve this task, mathematical models and planning procedures which take into account the real reservoir characteristics have been worked out.

The paper deals with the question of the state of thermal recovery methods application in the USSR. Major attention is paid to the results of testing the combined technologies. Their advantages in comparison with traditional technologies of thermal reservoir stimulation are demonstrated. In particular, it is shown that application of the combined technologies in the areas which are completely developed led to high oil recovery values with reduced requirements of power-intensive working agents for oil production.

In the years 1981-1984, oil production by application of the combined technologies increased on average 25-30% annually. The paper describes the characteristics of the major commercial scale projects using the combined methods for heavy-oil field development.

Résumé. En URSS des technologies économisant l'énergie, basées sur l'emploi combiné de méthodes thermiques et d'injection d'eau, ont été essayées et mises en oeuvre pour la production de bruts lourds. Cette technologie combinée aboutit à la création et à la propagation de bouchons de chaleur au sein de la formation. Elle permet de réduire considérablement la consommation des fluides injectés (vapeur et air comprimé exigeant une forte consommation d'énergie) pour la production du pétrole brut.

De ce fait, l'optimisation du maillage et de l'espacement des puits, des conditions d'injection et de soutirage des fluides, de la taille des bouchons thermiques a une grande importance. Pour résoudre ces problèmes, on a établi des modèles mathématiques et des procédures de planification qui tiennent compte des caractéristiques réelles des réservoirs.

La communication fait le point sur l'emploi des méthodes thermiques de récupération assistée en URSS et attire l'attention sur les résultats des essais des technologies combinées dont elle montre les avantages par rapport aux technologies classiques de stimulation thermique. En particulier, elle fait apparaître que l'emploi des technologies combinées dans les zones dont l'exploitation atteint son maximum permet d'obtenir des taux de récupération élevés avec de moindres besoins en fluides injectés pour la production du brut.

Pendant les années 1981-1984, la production du pétrole brut avec l'emploi des technologies combinées a augmenté en moyenne de 25-30% par an. On présente ici les caractéristiques des grands projets de taille commerciale utilisant les procédés combinés pour l'exploitation des gisements des bruts lourds.

1. INTRODUCTION

In the past few decades in the USSR research work has been done aimed at enhanced oil recovery (EOR). The main advance in this work was waterflooding techniques, widespread implementation of which allowed a significant increase in oil recovery, and in a short time the USSR was able to become a leader in oil production. Waterflooding techniques became universal because their application in oil fields with a wide range of geological and physical reservoir characteristics was accompanied by high technico-economic results. Simultaneously with increased oil production, more attention was paid to development of oil fields with so called 'difficult' oil reserves where waterflooding was of small effect. This mostly refers to heavy oil fields, where thermal techniques are widely used to increase effectiveness. In the USA, for example, oil production by thermal techniques is about 26 million tonnes annually. In the USSR thermal techniques in combination with flooding are used on a large scale for the development of such fields. This combined reservoir stimulation makes it possible to cut down on the expenditure of power-consuming working agents (steam, compressed air) for oil production. Feasibility studies and field tests of the combined technologies were initiated in the fifties and commercial application of them was carried out in the late sixties.

2. DEVELOPMENT SYSTEMS

The basic principles of thermal techniques in the USSR for EOR are as follows:

- Reservoir thermal stimulation is carried out together with waterflooding by creating and driving thermal slugs in the reservoir.
- Well patterns should be in rows or less intensive areal ones for better control of the development process.
- Creation of linear thermal fronts.
- Transfer of working agents for more rational heat utilization and thermal slug size correction.
- Optimization of well spacing density, injection and fluid production techniques, thermal slug sizes for ultimate utilization of thermal and hydrodynamic interference of layers with different permeability.
- Carrying-out cyclic reservoir stimulation for intensive oil recovery from reservoirs of low permeability.
- Carrying-out selective thermal treatment of producing wells bottom-hole zones to regulate heated zone migration and oil displacement.

For the first time new development systems were used in Okha heavy oil field, where steam injection with waterflooding was implemented in 1968 first as a pilot project then on a commercial scale.

Analogous development systems are being applied in such oil fields as Kenkijak, Karazhanbas, Usa, Balakhany-Sabunchi-Romany (Khorasany area) etc. At present more than 80% of oil in the USSR is recovered by thermal techniques. In 1981-1985 oil production using combined technologies application increased on average 25-30% annually.

3. THERMAL SLUGS

The essence of use of combined technologies with thermal slugs is as follows. While injecting a heat carrier, e.g. steam, a heated zone of a definite size is created near injection wells and then 'pushed' in the reservoir towards producing wells. It is also possible to use alternative injection of a heat carrier and cold water, i.e. a system of thermal slugs. Calculations indicate that a change to thermal slugs does not practically influence oil recovery. At the same time implementation of thermal slugs allows the use of more rational power equipment, specifically to accelerate oil production increase by thermal recovery.

The next basic method of thermal slug creation consists in use of damp and superdamp *in situ* combustion.

Test results allowed us to formulate the basic implications for the implementation of combined techniques.

First, we have to note a significant decrease of reservoir heating effectiveness as the heating process continues due to heat waste to surrounding rocks. This amount of wasted heat may be very large (80% of injected heat or more). So from a practical and economic point of view it is not advisable to heat the reservoir permanently.

The second implication for thermal slug application consists in a decrease in oil recovery rates at a certain stage of permanent reservoir heating. This can be explained, on the one hand, by a growing lag between a heated zone and a displacement front, and, on the other hand, by a considerable decrease of reservoir residual oil saturation long before the heated zone reaches the producing wells.

Hence, at a certain stage of reservoir permanent thermal treatment, power-consuming working agents (heat carrier, air) are used mainly for displacement or for maintenance of reservoir pressure. In view of this it is possible and necessary to change to the injection of a cheaper working agent, i.e. water, without preheating at a certain development stage.

The third implication for thermal slug application consists in the high efficiency of thermal stimulation of reservoirs characterized by high heterogeneity. It was shown that from the point of view of thermal effectiveness such reservoirs characterized by inclusions, interlayers, blocks etc. up to several metres in size, may be considered practically homogeneous. Under this condition it is easier, firstly, to create a thermal slug, and secondly, to decrease its 'spreading' during displacement because of reservoir heterogeneity. Lastly, a change from permanent reservoir heating to combined techniques is accompanied by a better relation between the mobility of an injected agent and displaced oil resulting in increased oil recovery. This is the fourth implication for the use of thermal slugs.

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4. SYSTEMS OF THERMAL STIMULATION AND WELL PATTERNS

It is preferable to locate wells in rows. Then, as a rule, there are three rows of producing wells between two rows of injection wells.

These are the well patterns used in practically all commercial projects where thermal techniques are applied for EOR. Besides this there are less intensive areal well patterns (inverted 7-spot, 9-spot pattern etc.). One of the main advantages of row well patterns is that it helps to create linear thermal fronts, thus providing for a high coverage of reservoirs by thermal stimulation. Linear thermal fronts are usually formed by injection of thermo-energetic agents (air, heat carrier) in every second well of the injection row with simultaneous forced fluids withdrawal from neighbouring wells in the injection row. After the linear thermal front is created, the neighbouring wells in the injection row are shifted to working agents injection. For a high efficiency of thermal recovery, working agents are finally injected into the producing wells of the nearest row of producers.

5. OPTIMIZATION

Thermal techniques of reservoir stimulation are considered to be power consuming processes. More than 70% of power consumption occurs through generating heat carriers and compressed air. Therefore, in choosing an optimum development variant the great significance is the effect on energy, expressed as a difference between oil recovery factor and the amount of oil reserves, spent for steam (compressed air) generation. The results of numerical reservoir simulation for steam injection combined with waterflooding of homogeneous reservoirs account for the fact that the maximum energy efficient oil recovery can be achieved by increased rates of injected working agents, well pattern thickening, and larger volumes of thermal slugs, i.e. intensive development variants. A further improvement of combined technologies is related mainly to the development of measures to overcome the negative impact of reservoir heterogeneity on the oil recovery process.

Optimization in wells pattern thickness, injection and liquids production rates, primary thermal slug volumes and other parameters controlling the recovery process, make it possible to use thermal interference of layers with different permeability, thus leading to greater oil recovery from low-permeable productive formations.

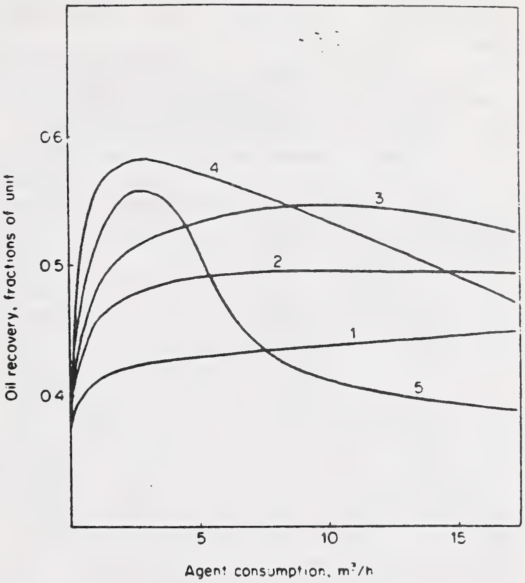

Fig. 1. Relationship of oil recovery factor against injected agent rate when volumes of slugs equal to 0.2; 0.5; 1; 2; 3, curves 1, 2, 3, 4, 5 correspond.

Calculations performed for stratified heterogeneous reservoirs are shown in Fig. 1. (relationship of oil recovery factor against injected agent rate). It is obvious that in permanent steam injection (curve 5) while using thermal slugs, the relationship of oil recovery factor to injected agent rate has an extreme character. If the sweep efficiency in a homogeneous reservoir increases due to enlarged heat injection leading to a relative decrease of heat losses in the surrounding rocks, then an increased injection rate in a heterogeneous reservoir decreases heat losses in the surrounding rocks but the heat losses increase per unit of produced liquids.

Such an opposite character of heat losses changes determines an optimum heat carrier injection rate into a heterogeneous reservoir to provide ultimate oil recovery. These peculiarities of the oil recovery process from a heterogeneous reservoir by permanent heat carrier injection are also true for thermal slug creation.

Choosing an optimum slug volume provides for maximum oil recovery.

Figure 1 shows that there are such optimum thermal slug volumes that allow oil recovery to exceed that obtained during permanent steam injection (curves 4 and 5). It is clear from calculations that this peculiarity of heterogeneous reservoir development is determined by the character of oil recovery from reservoir separate interlayers.

Thus, steam drive together with waterflooding in a heterogeneous reservoir may account for higher technological indices of oil fields development, oil recovery in particular, compared to permanent steam injection.

The indicated peculiarities and advantages of steam drive combined with waterflooding are also valid for *in situ* combustion.

In this case optimization of the process is closely connected with size determination for the primary thermal slug (saturated steam zone) created by damp or superdamp combustion before waterflooding. In the displacement process of a thermal slug in the reservoir by injected water, the slug is cooled down due to heat penetration zone interaction with the surrounding rocks. Further water injection is of no purpose if the slug temperature is below a definite limit when the advantage of thermal stimulation is exhausted. At this stage it is necessary to start injection of an oxidizing agent, thus creating the second thermal slug. Calculations made for specific conditions of oil fields in the USSR indicate a possible reduction of oxidizing agent volume by a factor of two or more in the case of thermal slug application.

6. APPLICATION

Thermal techniques of reservoir stimulation are used and tested in a wide range of geological and physical conditions (Table I). At present, the projects where combined technologies are applied account for more than 75% of total oil production by thermal recovery. The characteristics of field tests in the main projects and combined technology application are presented in Table II.

TABLE I

Range of thermal method application parameters

	Thermal stimulation	*In situ* combustion
Oil viscosity, mPa · c	7.0-20 000	1.3-900
Depth, m	50-1200	80-1800
Porosity, %	17-30	15-43
Permeability, mkm^2	0.06-4.0	0.03-5
Oil saturation, %	50-87	48.0-80.0
Net pay thickness, m	9.1-38.0	6-35.6
Well spacing density, hectare/well	0.05-3.1	0.6-9.0

In 1955-1956, in the Urich area of the Skhodnickoye oil field, it became possible for the first time under field conditions to transfer a thermal slug, created around an injecting well, into the reservoir depth by cold water injection[1]. Oil production of these drowned wells increased 3-8 times due to the stimulation.

On a commercial scale a method of steam drive followed by flooding was first applied in Okha oil field to recover high viscous oils[2]. Pilot tests in the oil pool of the fourth pay unit, *X*th block, where steam injection was initiated in 1968, preceded commercial application of the method. Development indices of the fourth pay unit, *X*th block, are given in Table III. The volume of the injected steam in the oil pool reached its maximum in 1973, when it was decreased continuously, and by 1977 was 148 thousand tons. The injected steam volume decline was accompanied by an increasing volume of injected water. In 1979 a change to pushing the created thermal slug by cold water was initiated. Further steam injection was carried out into poorly heated sections of the oil pool, increasing the sweep efficiency by thermal stimulation. The total amount of the injected agent at present is about 15 million tonnes, or 2.22 of pore volume. Oil production reached its maximum in 1972-1973. In subsequent years oil production decreased with an increase of total liquid production. This indicates, that the oil pool is in a stage when the thermal slug is being pushed by cold water. The

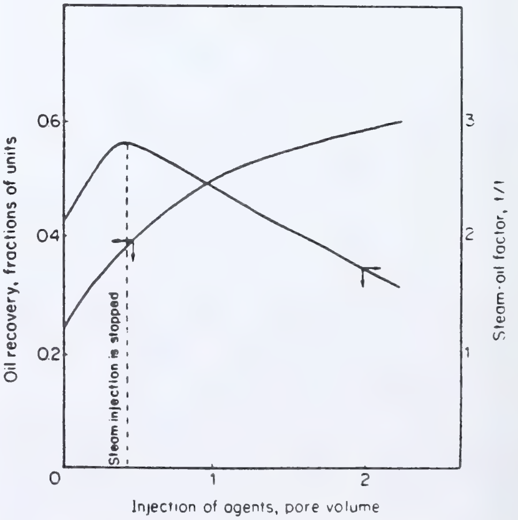

Fig. 2. Dynamics of oil recovery and steam-oil factor in oil pool of the fourth bed, *X* block, Okha oil field.

TABLE II

Main field data for complex technology application

Oil field	Depth, m	Reservoir thickness, m	Porosity %	Permeability, 10^{-3} mkm^2	Oil density Reservoir temperature °C	Viscosity under surface conditions, g/cm^3	reservoir conditions, mPa · c
Okha	100-460	22-35	27	1500	8	0.950	1200
Katangli	80-150	18-35	29	3850	7	0.936	2000
Eastern Ekhabi	650-700	10.5	28	600	15	0.940	210
Jarega	180-200	28.1	24	3200	7	0.940	11 000
Zybza	690-710	15	22	2500	30	0.976	300
Kenkijak	300-400	28	30	4000	20	0.915	180
Borislavskoe	4500-5000	30-50	20	1-120	18	0.860	5-7
Khorasany	400-600	15	24	218	36	0.934	55
Puta-Kuskana	610-660	18	24	100	30	0.915	23
Binagady-Kirmaku	500-700	12.5	24	56	32	0.918	80
Karazhanbas	220-500	2-33	28	30-3500	25	0.93	660
Usa	1100-1500	200	—	2300-30 000	23	0.943	710

TABLE III

Development index values of the fourth bed, *X* block, Okha oil field

	Volumes of injected agents				Oil production		Oil production per 1 well			
Years	steam, thous. t	cold water, thous. m^3	Number of injection wells steam/water	Volumes of injected agents, pore volume fractions	oil, thous. t	liquid, thous. m^3	oil t/day	liquid m^3/day	oil recovery	Specific steam consumption, t/t
1968	69.1	-	6/-	0.010	30.4	76.5	1.09	2.74	0.265	2.27
1969	152.1	25.8	5/2	0.034	65.5	165.5	1.58	3.98	0.279	2.30
1970	234.4	154.9	20/2	0.088	94.6	286.5	1.98	6.00	0.298	2.39
1971	305.9	274.1	18/8	0.168	117.9	400.8	2.25	7.65	0.323	2.47
1972	441.6	415.5	27/10	0.286	145.5	702.2	2.79	13.48	0.353	2.65
1973	469.5	559.6	26/14	0.428	145.0	848.2	2.99	17.47	0.383	2.79
1974	312.2	722.9	15/15	0.571	121.6	838.0	2.75	18.97	0.409	2.75
1975	174.3	735.0	16/17	0.697	119.7	800.5	2.67	17.85	0.433	2.57
1976	180.2	652.3	8/28	0.811	115.3	918.4	2.50	19.93	0.458	2.45
1977	148.0	786.2	9/19	0.940	108.0	900.2	2.29	20.14	0.480	2.34

natural drop in production in the process of oil pool depletion is associated with a decline of power consumption for oil recovery due to modified technology application. In the period 1973-1985, specific consumption per 1 tonne of produced oil dropped from 2.79 to 1.68 tonnes. The dynamics of oil recovery and steam-oil ratio in the pool are shown in Fig. 2. Overall, in the Okha oil field the steam-oil ratio does not exceed 3 t/t.

For better regulation of the process a linear system of thermal stimulation was used in the pool of the fourth pay unit, *X*th block. Producing wells pattern are shown in Fig. 3. In the VIIIth block, water and steam is injected in two rows of injection wells—eastern and western.

Steam injection was initiated in 1973 in wells of the eastern row. Injection wells in the row alternated with neighbouring producers. In 1976 these wells were put to water injection and neighbouring producers were transferred to steam injection. The same year, steam injection was initiated in wells of the western row, 3.04 million tonnes of steam or 0.58 of pore volume was injected into the oil pool by the beginning of 1985. Maximum annual volume of injected steam

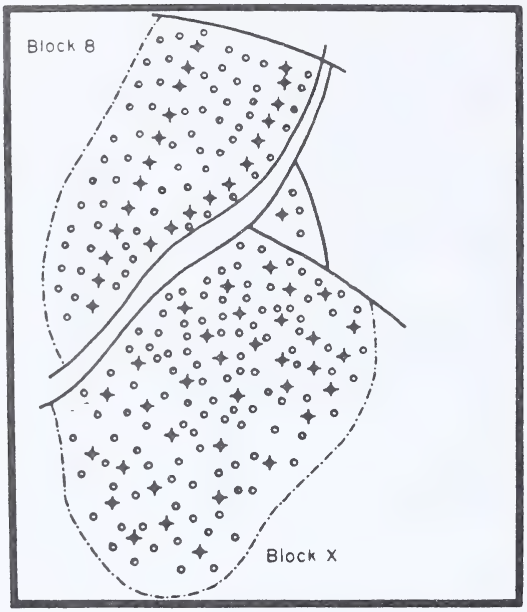

Fig. 3. Producing wells pattern in oil pool, Okha oil field.

(367 000 tonnes) was reached in 1976, in 1984 it declined to 128 000 tonnes. Injected water volume increased from 196 000 m^3 in 1976 to 790 000 m^3 in 1984. Total injected steam and water in the pool amounts to 1.44 of pore volume. During stimulation, oil recovery increased more than twice with a steam-oil factor reduction from 4 t/t (in the beginning) to 3 t/t.

The oil field development is still in progress but even now it is possible to summarize certain results:

- It was possible to increase oil production from a practically exhausted oil field up to the initial productive development stage.
- Oil recovery of the fourth pay unit, *X*th block, development of which is near completion, reached 60%.
- The total current oil recovery of the oil field increased twofold.
- Specific steam consumption for oil production is about 3 t/t on the average.
- Permanent high level of oil production in the oil field has been maintained for some 10 years.

Realization of steam recovery in the oil fields of Azerbaijan was of great importance to raise the oil production level since the traditional stimulation methods were unable to provide for high rates of oil recovery. Steam injection in PKS_1 horizon of the Khorasany area promoted a significant increase of average daily production rates. In the period of permanent steam injection the incremental produced oil volume amounted to 34% of oil cumulative production.

From 1976 the whole area of steam stimulation was converted to the thermal slug shifting process, using cold water as a 'pusher'. The results of this process are given in Table IV. In comparison to the completion period of permanent steam injection, steam consumption per tonne of produced oil declined 2. 3 times and the incremental produced oil volume increased by 13%[3].

In the Binagady-Kirmaku and Puta-Kushkhana areas thermal slug shifting, created by permanent steam injection, was carried out by cold water, using a thickening agent[3]. In all the areas due to thermal slug transfer by the injected water a certain technological effect was obtained (Table V). Incremental produced oil volume from the beginning of the process initiation in the Khorasany area was 46.8%, in Binagady-Kirmaku 38.7% and in Puta-Kushkhana 26.6% as compared to steam injection without flooding.

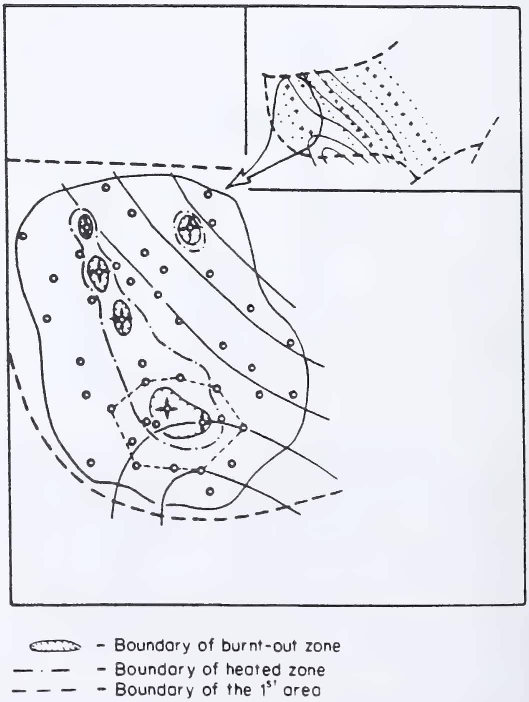
- Boundary of burnt-out zone
- Boundary of heated zone
- Boundary of the 1st area

Fig. 4. Linear thermal front in Khorasany area.

TABLE IV

Parameters of steam stimulation in Khorasany oil field

Years	Steam-oil factor, thous. t		Water-oil factor, thous. t		Incremental produced oil volume, % of total production
	per 1 t of summary production	per 1 t of additional production	per 1 t of summary production	per 1 t, of additional production	
1976	3.8	10.1	5.3	12.6	43
1977	3.3	8.3	3.9	8.1	55
1978	2.9	7.2	3.7	7.4	51
1979	2.7	6.3	3.7	7.3	55
1980	2.4	5.7	3.6	7.0	52
1981	2.1	5.1	3.4	6.8	54
1982	1.9	4.5	3.0	6.5	56

TABLE V

Parameters of steam stimulation in Azerbaijan oil fields

Oil field	Volume of injected steam, thous. t.	Steam injection duration, years	Incremental oil produced volume, % of total production	
			steam injection	thermal slug displacement
Khorasany	348	6	26.6	60.9
Binagady-Kirmaku	100	4	20.6	64.7
Puta-Kushkhana	16.4	1.2	31.5	45.9

Experience in the implementation of thermal stimulation in the Azerbaijan oil fields is connected with realization of damp *in situ* combustion in the following areas such as Khorasany, Koshanaur, Surakhany and Karachukhur. In the Khorasany area, in particular, it was possible for the first time to create a linear thermal front under the conditions of wells located in rows (Fig. 4). High displacement efficiency was achieved (more than 57%) from the reservoir regions subjected to thermal stimulation, though according to core analysis the combustion front has passed through layers comprising only $\frac{1}{3}$ of the total net pay thickness. Fig. 5 shows the dynamics of oil production from initial oil reserves and air-oil ratio for the first pilot area, where in 1973 the introduction of the method in PK_t horizon was initiated. Decline of the air-oil ratio indicates a change to the realization of stable damp *in situ* combustion.

The lowest value of air-oil ratio is related to a change to pushing of the created thermal slug by cold water. Fig. 6 shows the dynamics of technological indices of horizon PK_t's development in Khorasany.

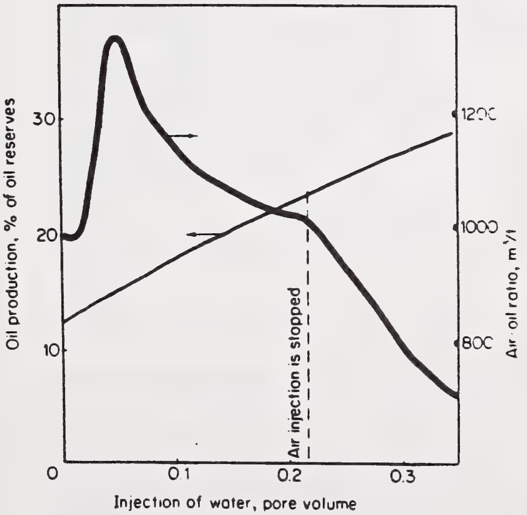

Fig. 5. Dynamics of oil production from the initial oil reserves and air-oil ratio for the first pilot area in Khorasany.

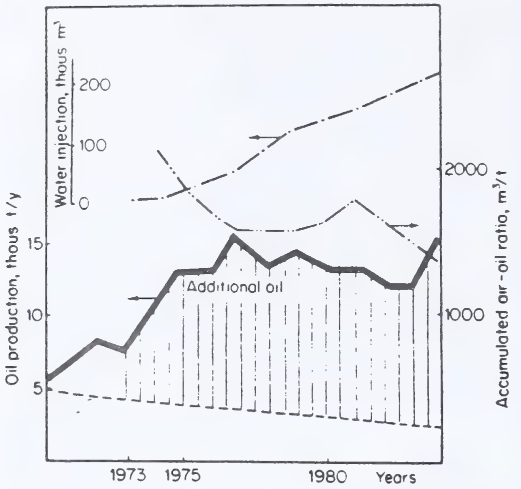

Fig. 6. Dynamics of technological indices of horizon PK_t's development in Khorasany.

Specific air consumption per tonne of produced oil is about 600-700 nm^3 at present. Due to the cooling of the thermal slug during two years of cold water injection there was a temperature decline to 105-107 °C. Fig. 5 shows oil production vs. years from initial oil reserves. A 5% increase of oil recovery in the period of pushing the thermal slug by cold water, indicates the high thermal potential of the reservoir and the technological efficiency of the process in the pilot test area. Current annual oil production is twice as high as before the experiment started.

Practical experience obtained in the Okha oil field and in Azerbaijan made it possible to spread the new systems of oil field development and to stimulate progress in testing and application in Kazakhstan, Bashkiria, Komi ASSR, Ukraine and other oil producing regions of the country.

In the Karazhanbas oil field, application of steam recovery and damp *in situ* combustion followed by waterflooding is carried out on a large scale. The created thermal slugs of appropriate size are then shifted by cold water (Fig. 4).

The process of *in situ* combustion was initiated in 1981 in two inverted 7-spot patterns.

Intensive forming of vast heated zones in front of combustion made it possible to change to the creation of linear systems of thermal stimulation after *in situ* combustion initiation in other injection wells. In accordance with the projected technology a change from dry combustion to damp and superdamp takes place. By the end of 1985 practically all the producers in the area used *in situ* combustion, initiated in 44 injection wells. In the final stage in the first row of injection wells, superdamp *in situ* combustion was carried out with water-air ratio of about 0.05 m^3/nm^3 and more. Fig. 7 shows a map of CO_2 changing content in combustion gases at the moment of linear thermal front creation in the first row of injection wells. This map gives a precise outline of withdrawal points within the limits of which wells actively react to *in situ* combustion. Specific air consumption of not more than 500 nm^3 per tonne of produced oil indicates a high technical and economical use of the process.

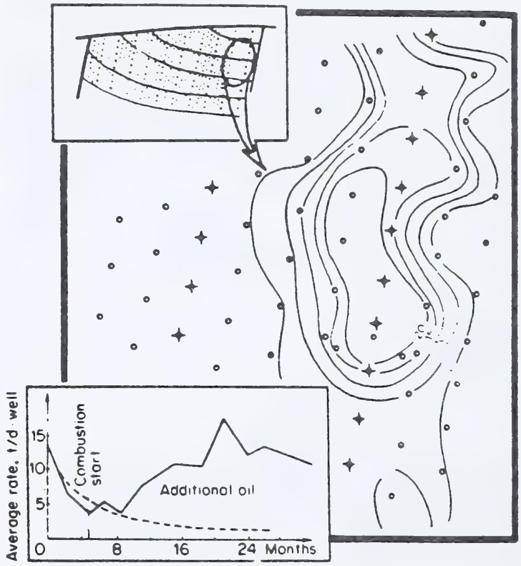

Fig. 7. Map of CO_2 changing content in combustion gases to the moment of linear thermal front creation in Karazhanbas oil field.

Basic indices of oil field development by *in situ* combustion are given in Table VI. Field tests unanimously proved the advantages of the linear 3-row system of stimulation in comparison to single-row or areal 7-spot pattern systems.

The steam recovery process in the Karazhanbas oil field was initiated in 1982. At present working agent injection is performed in 43 injection wells concentrated in 5 rows. The stage of shifting the created thermal slug by cold water was performed in one row; in two rows of injection wells a thermal slug is being created by cyclic injection of steam and water. In two rows located in the most productive regions of the reservoir a thermal slug is being created by permanent

TABLE VI

Development index values of *in situ* combustion in Karazhanbas oil fields

Years	Air injection, mln. m^3	Oil production due to method application thous. t.	Accumulated air-oil factor, m^3/t	Number of wells	
				producing (responding)	injection
1981	4.7	21.0	223	21	4
1982	18.0	110.0	164	55	13
1983	63.0	186.0	339	85	30
1984	89.0	210.0	424	122	40
1985	138.1	211.3	420	124	45

TABLE VII

Development index values of steam stimulation in Karazhanbas oil fields

Years	Steam injection thous. t.	Oil production due to method application thous. t.	Accumulated steam-oil factor, t/t	Number of wells	
				producing (responding)	injection steam/water
1982	5.5	-	-	-	5
1983	417	85	5.0	50	25
1984	154	187	2.1	122	35
1985	304.5	120.9	2.2	153	37/6

injection of a heat carrier. The dynamics of the basic indices of oil field development are given in Table VII.

Current accumulated steam-oil factor does not exceed 2.2 t/t, and more than 85% of total wells respond to the thermal stimulation process.

Steam recovery technology in Kenkijak was implemented in two stages. In the first stage a thermal slug of 0.6-0.8 pore volume of the treated reservoir was created; the second stage envisages displacement of a thermal slug by cold water[4]. Wells are located in rows across the trend of the reservoir. In 1978 a linear three-row system of well pattern was tested.

Oil recovery in the first field test reached 40% compared to 4% before the initiation of stimulation. Additional oil production from the beginning of the process is more than one million tonnes. The technological efficiency of the process is characterized by dynamics of average well production rate in the field test area of top priority, shown in Fig. 8.

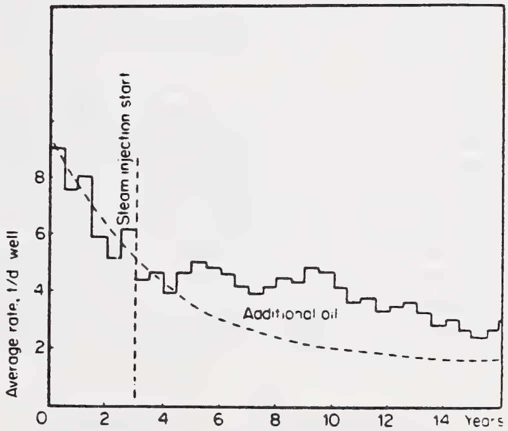

Fig. 8. Dynamics of average well production rate in the field test area of top priority of Kenkijak oil field.

The main goal of the experiment in the Usa high-viscous oil field was to evaluate the technological and economical effect of steam recovery application in depths lower than 1000 m in a carbonate fractured reservoir of high thickness, i.e. under extreme conditions for this method[4]. The existing technology of steam recovery was tested there, that is to inject steam in quantity of 0.6 pore volume followed by cold water injection for thermal slug pushing. Injection and producing wells will also undergo steam cyclic treatment.

The initial stage of field tests reveals the necessity of cyclic stimulation with periodic redistribution of

TABLE VIII

Development index values of Usa oil field

Years	Steam injection, thous. t.	Oil production due to method application, thous. t.	Accumulated steam-oil factor, t/t	Number of wells	
				producing (responding)	injection
1982	323.4	70.6	4.6	22	5
1983	762.9	172.3	4.5	22	6
1984	797.6	290.6	3.5	72	15
1985	951.2	441.6	2.9	51	13

liquids withdrawal points due to a low summary sweep efficiency.

The change to cyclic stimulation was carried out in 1984. Before injection, wells shutoff water of most producers was cut 50% and more. Shutoff of injection wells and bringing them back into production significantly improved the operation of producing wells. Oil productivity of wells increased 1.5–3.0 and more with a sharp decline of production water cut.

On the whole, the technology of steam stimulation in the Usa oil field is being introduced successfully. Basic index dynamics of the development are given in Table VIII.

This is a short description of thermal stimulation application in several oil fields of the USSR. The method of steam stimulation in experimental and field tests in the USSR is being applied in 22 projects of 19 oil fields, and *in situ* combustion in 17 projects of 13 oil fields.

The achieved value of a steam-oil factor in the different projects is 2–4 t/t on average, which is much lower than observed (4–6 t/t) while implementing the older technology of permanent steam injection. Application of thermal slugs when oxidizing processes take place under reservoir conditions helps to reduce the volumes of an oxidizer 1.5–2 times for oil recovery. In addition, by thoroughly studying flooding stage technology, it allows us to solve problems related to the regulation of development processes, more accurately.

7. IMPROVEMENT OF TECHNOLOGY

The advantages of thermal method implementation for field development with high-viscous oils diminish under unfavourable geological conditions. The negative influence of reservoir heterogeneity when using thermal techniques is aggravated by the poor mobility relationship between injected and displaced fluids.

A promising development in this respect, is a system for technological processes that will provide for selective introduction of agents, improving oil displacement, i.e. creation of a 'self-adjusting' technological scheme. This may be a combination of thermal and physical-chemical methods, for instance thermal slugs and polymers, alkali, foam systems etc.

To get over the difficulties arising in the process of thermal technique application at great depths, it is possible to integrate heat-carriers injection technology and that of damp *in situ* combustion. First of all a complex of technological procedures providing for hot water injection together with air into the formation is such a promising complex technique. Hot water injection may ensure reservoir temperature rise to 90–100 °C and higher, which will create reliable conditions for almost complete utilization of the oxygen injected in the reservoir. In addition, with oxygen injection into reservoir sections, heated by hot water, intensive oxidizing processes occur, turning the injected hot water into steam under reservoir conditions. Amounts of injected hot water may be significantly reduced, so making it easier to create reliable and economical construction of an injection well and also a mobile and cheap bottom hole heat generator. Furthermore, the reduced volumes of injected air will make the problem of liquids production easier.

The basic solution of the problem for reducing produced gas volumes consists in injection of pure oxygen or air enriched with oxygen to maintain *in situ* combustion. Carbon dioxide thus formed in the reservoir is a more effective agent for increased oil recovery than when it is significantly diluted by nitrogen from the air.

The improvement of thermal techniques for EOR, consisting in integration of injection methods of heat-carriers and air (as an oxidizing agent), may thus lead to a considerable widening of thermal stimulation application.

The combination of complex thermal techniques for EOR, together with relatively simple physical and chemical means of reservoir treatment (for instance, thickening agents, foaming agents, alkali solutions etc.) as well as with specially organized alternate practices of injection and production of liquids and gases, may become a base for creating new complex systems of oil field development.

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GEOLOGICAL PROBLEMS OF NATURAL BITUMEN

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Abstract. Keen interest in the investigation of natural bitumens in the USSR is connected with the recent discovery of shallow bitumen accumulations in various regions of the country, that are of commercial importance. The paper describes the processes of bitumogenesis and genetic types of natural bitumens. The classification is given, based on definition of the series grouped by commonality of the processes of formation and conditions of occurrence of natural bitumen accumulations (NBA). It is found that NBA of hypergenous and phase-migrational series are most widely spread. The basic principles of the location of NBA in the oil-gas-bearing or bituminous basins have been analysed, among which four types are defined. Specific features of the geological structure of typical accumulations of natural bitumens in the Volga–Urals and Leno–Anabarsky basins have been considered. The geologo-economic problems of NBA production in the USSR have been discussed, among which the particular attention is paid to comparability of the predicted costs of production of natural bitumens and conventional oil. The conclusion is made in regard to importance of the complex use of natural bitumens with the account of the rare elements' content in them.

Résumé. Le grand intérêt porté en URSS à l'étude des bitumes naturels est lié à la récente découverte d'importants gisements peu profonds dans certaines régions du pays.

La communication étudie les processus de bitumogenèse et les types génétiques des bitumes naturels et donne une classification basée sur la définition de séries groupées en fonction des conditions de formation et de la localisation des gisements. Elle trouve que les gisements des séries supergènes et ceux à migration de phases sont les plus répandus. Elle étudie les règles principales de répartition des bitumes naturels dans les gisements pétroliers et les bassins de bitume dont on distingue quatre types. Elle décrit les caractéristiques de la structure géologique des gisements typiques de bitumes naturels dans les bassins de Volga–Ourals et de Leno–Anabarsk.

Elle discute des problèmes géologiques et économiques du développement des gisements de bitumes naturels en URSS, en accordant une attention particulière à la comparaison des coûts prévus de production des bitumes naturels et du pétrole brut classique.

En conclusion elle souligne l'importance de l'emploi diversifié des bitumes naturels, compte tenu des éléments rares qu'ils contiennent.

INTRODUCTION

Aggravation of energy problems in the world has resulted in keen interest in the production of almost inaccessible non-traditional types of hydrocarbon raw material; among these heavy oil and natural bitumens (NB) are considered most important. Original, potential recoverable resources of these kinds of raw material are commensurate with the resources of 'normal' oil. Heavy oil and NB are reliable sources for obtaining 'synthetic' oil and, therefore, their production promises at least a tripling of oil reserves in the world. In spite of this, the intensity of prospecting for them is only about one tenth that of 'normal' oil. Prospecting intensity is particularly low throughout the world in regard to NB. However, NB are widely spread in nature. The low level of investigation of the main principles of NB formation and mode of occurrence in the Earth's crust is typical even for regions, where potential resources of NB are considerable. This is mainly explained by the absence in the past of the necessary economic stimulus for the wide commercial production of natural bitumen accumulations (NBA). Obtaining 'synthetic' oil from NB requires considerably higher expenses in comparison with production of 'normal' oil. Therefore, only current production of the most productive and shallow accumulations, similar to huge and unique accumulations, such as the Orinoco bitumen belt in Venezuela and Western-Canadian bitumen basin, is of a commercial importance.[1]

11th World Petroleum Congress, London, Aug. 28-Sept. 2, 1983

Keen interest in the investigation of NB in the USSR is connected with the fact, that during the last decade upon prospecting and exploring oil fields NBA were discovered at the same time in shallow easy-accessible and sufficiently studied regions of the European part of the USSR territory (Volga–Urals region), as well as in the north of the European part and in East Siberia. These findings suggest a wide areal distribution. Consequently, a wide systematic investigation has begun. As a result, some general principles of the occurrence and peculiarities of NB structure were determined; commercial importance of the discovered accumulations was ascertained; perspectives of new discoveries were evaluated; the first-order trends for possible prospecting were detected and the tasks of the further complex investigation of the problems of NB geology were formulated.

1. PROCESSES OF BITUMOGENESIS AND GENETIC TYPES OF NATURAL BITUMENS

The term 'natural bitumens' (NB) designates hard, viscous and viscous-plastic derivates of oil and their analogues. They constitute a wide spectrum of organic compounds consisting of high-molecular hydrocarbons and heteroatomic compounds. The boundary between viscous bitumen (maltha) and oil is defined by various parameters: density, viscosity, coking capacity and content of oil components.

The rheological characteristics of bitumen depend mainly on colloid structure and only superficially on chemical composition. In many cases, a discrepancy of classification boundaries between oil and NB for physical and chemical parameters is observed.

Several classes of NB are defined, where the boundaries are established for a number of parameters mainly provisionally (Table I). Besides the parameters mentioned in this table, solubility of bitumen in organic solvents should be necessarily taken into account upon determining kerites and anthroxolites. For non-paraffinic bitumens, especially when the content of resinous impurities is high, the composition of the paraffinic fraction of hydrocarbons is a dominant parameter.

Among natural bitumens, maltho-asphalts and the associated group of high-viscous oils are of the most interest, that, in contrast to 'normal' oils, cannot be produced with the help of traditional methods.

TABLE I

Physico-chemical parameters of the basic classes of natural bitumens and high-viscous oils

Class of natural bitumens	Content, % of		Viscosity, consistency, Pa · s	Density, g/cu cm °API
	oil	asphalto-resinous components		
High-viscous oils	>75	<25	0.05–2	0.935–0.965 20–15
Malthas	75–40	25–60	2–20	0.965–1.03 15–5
Asphalts	40–25	60–75	20–1000	1.03–1.1 5
Asphaltites	<25	>75	>1000	1.05–1.20 5
Kerites	3–5, more seldom up to 10	>90	Hard, partly soluble in chlorophorm	1.07–1.35
Anthraxolites	not available	100	Hard, not soluble in chlorophorm	1.30–2.0
Ozokerites	In pure varieties 100, in impure up to 50	<50	Semihard, represented by paraffinic structures	0.85–0.97

Formation of the total NB range can be considered in the light of the idea about transformation of oils[2] as the consequence of displaying the following bitumogenesis processes.

(1) Oxidizing transformation of primary oils with formation of a series of asphaltic bitumen:

maltha → asphalt → asphaltite
→ oxykerite → humminokerite

(2) concentration of asphaltic-resinous components due to disturbance of the equilibrium state in the colloid oil system resulting in formation of a series of asphaltic bitumen, essentially of a vein type;
(3) natural deasphaltization of oils by gas or light paraffinic hydrocarbons upon multistage formation of oil, gas–oil and gas–condensate deposits with formation of hard bitumen-asphaltites: from asphalt to lower anthraxolites;
(4) differentiation of gas–condensate mixtures upon migration and formation (as a result of phase-retrograde processes) of hard bitumens of the paraffin series (ozokerites, hatchetites);
(5) thermal-metamorphic variation of resinous oils and bitumens with formation of high-carbonized varieties from kerites to petroleum coke;
(6) destruction of organic material under conditions of contact metamorphism with formation of wide spectrum of bitumens (naphthoids) of the asphaltic and paraffinic series characterized by properties of oil bitumens.

For genetic NB series under consideration, repetition of some groups and classes is typical, that is found to be one of the specific features of bitumogenesis. The basic NB mass and all its major accumulations are formed due to biochemical and chemical oxidation of primary oils (Table II).

In the process of transformation of 'normal' oils, enrichment of ash components of heavy oils and bitumens by a series of metals takes place. Concentration in NB of elements such as vanadium, nickel, cobalt, molybdenum, germanium, scandium, silver, etc. associated with asphaltic-resinous, basically asphaltene components of original oil, depends mainly on conditions of bitumen accumulation. In the physical processes of concentration of asphaltic-resinous fractions the content of metals in bitumens increases proportionally to the quantity of metal-carrying components precipitated from oil. In the processes of chemical oxidation essential enrichment of bitumens by metals does not take place. These factors allow prediction of the content of vanadium, nickel and the other metals in NB of different genetic types.

2. CLASSIFICATION AND CONDITIONS OF FORMING NB ACCUMULATIONS

The study of NBA showed extremely large diversity of conditions of formation, structural forms, occurrence and morphological characteristics.

Exploration for NBA and its successful realization are inconceivable without rational methodology prepared with due consideration of classification of NBA.

In the process of permanent investigation several classifications were suggested, that are used by various authors for description of natural bitumen accumulations (N. B. Vassoevich, N. A. Eremenko, S. P. Maximov); for investigation of modes of occurrence of bitumen accumulations (N. S. Shatsky), and for clarification of the pathways of bitumen transformation (V. A. Uspensky, O. A. Radchenko). In accordance with the designated purpose only one basic characteristic was put in the basis of these classifications.[3] Upon creation of rational methodology for prospecting and exploration activities this is not enough. Classification is required, taking into account at least two main factors: genesis and structural-morphological characteristics of the fields.

Formation of oil accumulations depends on structural, lithological and stratigraphic factors. For localization of natural bitumens, the nature and the direction of the processes of hydrocarbon transformation acquires an important role. Thus, a genetic principle should be put in the basis of the classifications of natural bitumen accumulations (Table III).

Bitumen accumulations can be typified by series of unidirectional processes of bitumogenesis: hypergenous (oxidizing), phase-migrational and thermal-metamorphic. The following groups of deposits can be defined, characterized by commonality of formation and conditions of occurrence: (1) the group of hypergenous series, where a sheet monocline type can be ascertained, that formed in the course of the migrational flow of oil in the reservoir (in the zones of essentially lateral infiltration of fresh water); sheet structural and the other types, formed in the place of primary oil accumulations diverted to the zone of water exchange and aeration; mantle (cover-type) deposits associated with subaeral transformation of flow-out oil; (2) deposits of phase-migrational series including fractured (vein, interlacing vein, fractured-sheet type), formed on the way of migration of hydrocarbon fluids enriched by bitumen-forming components (resins, asphaltenes, hard paraffins) through

TABLE II

Distribution of natural bitumens of various classes by genetic series

Genetics series	Dominating types of processes	Nature of original material	Genetic type	Group, subgroup	Typical classes, subclasses
1	2	3	4	5	6
Hypergenous (oxidizing)	Biochemical oxidation Evaporation of light fraction	Oil	Naphthides	Normal asphaltic bitumens (asphaltides)	Oil, high-resinous, heavy Malthas Asphalts
	Chemical oxidation	Oil: cyclic, resinous			Malthas Asphalts Asphaltite
	Residual accumulation of resinous and sulphurous compounds	Oil: paraffinic and naphthenic, low-resinificated		Brea	Malthas Asphalts Asphaltite
	Intensive chemical oxidation under subaerial conditions	Bitumens: asphaltic	Bitumens of various genetic types	Oxibitumens	Oxykerite Huminokerites
	Intensive bacterial oxidation in subaerial conditions	Bitumens: paraffinic			Algarites Elaterites
	Natural deasphaltization of oil by gas or light paraffinic hydrocarbons	Oil; relatively enriched by asphaltic-resinous components	Naphthides	Asphaltenites	Asphalts Asphaltites Kerites Anthraxolites (lower)

Phase-migrational	Concentration of asphaltic-resinous material due to disturbance of the equilibrium state in the colloid system of the flowing oil (evolution of solved gases, carrying-away of oil components)	Oil: resinous, heavy	Naphthides		Malthas Asphalts Asphaltites
	Phase-retrograde processes upon migration	Gas-condensates: heavy		Paraffinites	Oil: high-paraffinic (associate) Ozokerites Hatchetites
	Hydrothermal differentiation under conditions of the transfer of oil by hot solutions	Paraffinic oil			
	Pyrolysis under conditions of the contact and hydrothermal processes T °C: 900–600° (petroleum coke) 600–300° (anthraxolites) 300–100° (kerites)	Bitumen: asphaltic and oil: high-resinous, heavy	Naphthide-naphthoids	Asphaltoids	Kerites Albertites Impsonites
				Graphitoids	Anthraxolites Lower Middle Higher Petroleum coke
Thermal-metamorphic	Destruction of organic material under conditions of low-temperature process	Sedimentary rock rich in organic materials (coal, oil shale and others)	Naphthoids	Pyronaphthoids α-naphthoids	Classes: from malthas to anthraxolites
	Differentiation of sublimations of thermal springs			β-naphthoids	Hatchetites Chrismatites Olefinites, elaterites
	High-temperature pyrolysis and differentiation of sublimations	Essentially humus material		γ-naphthoids	Kertesites Carpatites
	Squeezing of bituminous components of organic material into fractures as a result of intensive stress (dynamometamorphism)	Sedimentary rock rich in organic material		Tectonaphthoids	Classes of asphalt and asphaltites

TABLE III

Genetic classification of natural bitumens

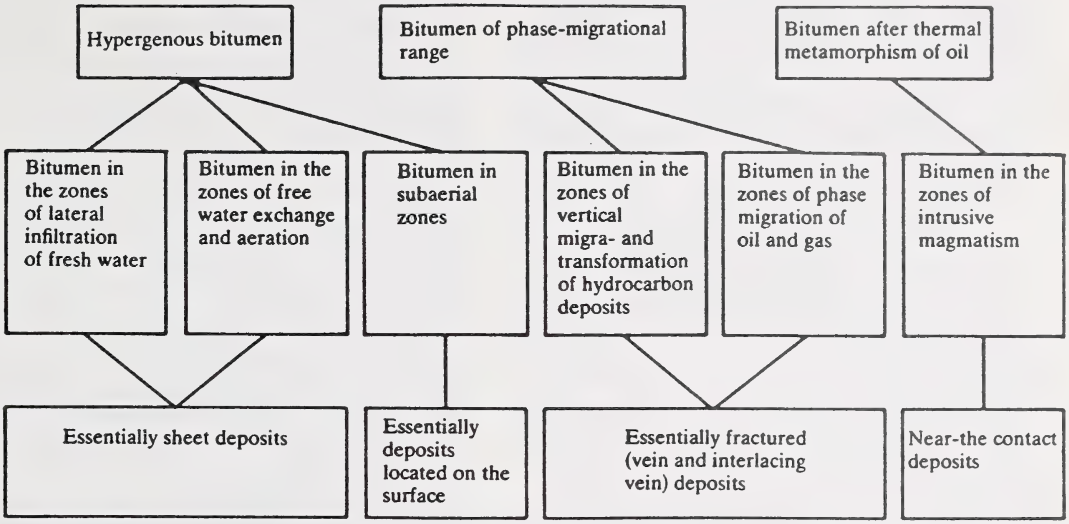
Hypergenous bitumen
Bitumen of phase-migrational range
Bitumen after thermal metamorphism of oil
Bitumen in the zones of lateral infiltration of fresh water
Bitumen in the zones of free water exchange and aeration
Bitumen in subaerial zones
Bitumen in the zones of vertical migra- and transformation of hydrocarbon deposits
Bitumen in the zones of phase migration of oil and gas
Bitumen in the zones of intrusive magmatism
Essentially sheet deposits
Essentially deposits located on the surface
Essentially fractured (vein and interlacing vein) deposits
Near-the contact deposits

TABLE IV

Classification of hypergenous and phase-migration accumulations of natural bitumen

Group	Class	Type	Accumulations
Fractured sheet	Structural	Arched	Arkanskoye, Moraovo-Karmalskoye, Djungurshy, Varandeiskoye
		Sheet-arched	Aksubaevskoye, Talotinskoye, Bugrovskoye, Kirmakinskoye
		Tectonically screened	Tyubedzhik, Kara-Murat, Iman-Kara, Chunkinskoye, Officina-Temblador and the other deposits of the Orinoco belt
		Sincline	Legkemskoye, Edna
	Stratigraphic	Stratigraphically screened	Izhemskoye
		Structural stratigraphic	Pereborskoye
		Erosional	Nyadeiyuskoye, Taspas
	Lithologic	Lithologically screened	Upper-Chimedenskoye, Wabasca
		Lithologically confined	Pervomaiskoye, Troekurovskoye, Neftyanoy Klyuch
		Lithologo-stratigraphic	Olenekskoye, Athabasca, Peace River
		Reefogenous-biomorphous	Ishimbaiskoye, Enikalskoye, Golubiniy Mis
	Vein	Anticline, diapir structure, feathering disruptures	Sadkinskoye, Starunskoye, Kairovskoye, Harball
	Interlacing vein	Zone of crushing and fracturing	Dzvinyachskoye, Borislavskoye
Mantle	Flow-out (seepage)	Brea hills, brea covers, brea hats	Asfaltovaya Gora, Binagadinskoye, Neftegorskoye, Selenitsa
	Asphaltic pools	Structural-erosional depressions	Bolshoe (Sakhalin island), Nutovskoye, La-Brea, Guanako

tectonic fractures; complicated structural-sheet type (bitumen-oil, bitumen-gas condensate, etc.), associated with the zones of multi-phase migration of oil and gas; (3) deposits of thermal metamorphic series including near-the-contact deposits formed by the action of intrusion on the primary oil and bitumen accumulations, etc.

NBA of hypergenous and phase-migrational series are most widely spread. Among the latter, the groups, classes and types of NBA (Table IV are defined by conditions of occurrence, genesis and the structure of monitoring traps. For some NBA combination of various types and groups of deposits is typical, that are composed of bitumen of various composition (for instance, fractured ozokerite deposits and mantle (cover-type) deposits-malthas, sheet structural maltha deposits and vein deposits; asphaltites and others).

Formation of huge and giant accumulations of natural bitumen, containing about 90% of world geological reserves of natural bitumen are of the most interest.

Formation models for such accumulations, where many ones in their reserves considerably exceed the oil giants (Athabasca 138.1 billion cu m, Cold Lake 43 billion cu m, Wabasca 18.9 billion cu m, etc.) cannot be prepared due to primary accumulation of normal oil in traps. Formation of giant bitumen accumulations proceeds only, when favourable conditions are available for further lateral migration of a considerable mass of oil from the generation zones into the marginal part of the basin (gently-sloping monoclines, uncomplicated at the bottom by large traps, development of regional permeable zones, etc.), where its preservation takes place due to oxidizing action of counter flow of infiltration water. Therefore, all accumulations of such a kind (group of sheet monocline deposits) are localized at the external monocline edges of large deeps, adjacent to the shields and deeply eroded archs that serve to feed fresh water into the areas. These accumulations are represented by malth-high-resinous oils and sometimes by asphalts.

The mechanism of forming the sheet structural deposits of bitumens is affected by the conditions of hypergenous transformation of primary accumulations of oil. In some basins, especially in the basins of the ancient platforms, destruction of oil deposits and formation of bitumen deposits on their place proceeded at numerous stages. As a result, the buried bitumen deposits are formed under the surface of the washed-out zones (for example, Pre-Visean, Pre-Kungursk, Pre-Triasic–Pre-Middle Jurassic in the Timano–Pechorsky basin and others). In erosional Hand paleoerosional arched deposits bitumens are usually represented by asphalts and asphaltites. In the arched deposits located below the erosional base bitumens are represented by malthas and heavy high resinous oils. Most structural sheet bitumen deposits occur within the large platform structures affected by an active elevation at the stages following the cycles of oil accumulation. Reserves of individual deposits reach several hundreds of million tons (Nyadeiyuskoye, Talotinskoye deposits and others).

The mantle (cover-type) subaeral bitumen deposits (malthas, asphalts, sometimes asphaltites) are forming at the outcrops of oil-bearing reservoirs (so-called brea deposits) or near the channels of the oil flow-out to the surface (brea beds, asphaltic pools, etc.). The largest deposits (asphaltic pools) containing bitumen reserves amounting to tens of million tons (La Brea, Guanaco, etc.) are confined to the internal edges of the Alpine marginal deeps and synclinal structures of the folded zones.[1]

Conditions of the formation of the homogenous bitumen accumulations in the fractures depend on combination of number of factors: availability of 'primary' accumulations of bitumen-forming fluids, heavy resinous oil (for asphalts and asphaltites), and heavy gas condensates or high-paraffinic associated oil (for ozokerites), as well as availability of disruptures, followed by development of open fractures. Availability of vein bitumen beyond the oil-gas-bearing regions, within anticlines and elevations in the folded regions, in particular, (Urals, Andes, Antillean, Zagros regions, etc.) indicates, probably, oil–gas-bearing capacity of these geosynclinal basins in the past. The thickest veins of asphaltic bitumen occur in the folded zones, reaching a width of 20–80 metres and a length of 1.5–3.5 kilometres (the Zagros–Harball vein systems and others).

3. BASIC PRINCIPLES OF LOCATION OF NATURAL BITUMEN ACCUMULATIONS IN OIL–GAS-BEARING BASINS

Genetic and spatial association of natural bitumens and their essential accumulations with oil–gas-bearing basins permits a consideration of the latter as the main entity for bitumen geological demarcation. Such basins comprise a group of the adjacent oil–gas-bearing and bitumen-bearing areas, where the difference between the areas is detected by peculiarities of the tectonic evolution and structure at the stages that complete the cycles of oil–gas accumulation, as well as at the stages, that follow them. The proportion of natural bitumen to the total mass of hydrocarbons, primary accumulated in the basin, depends on intensity of the evolution of one or another process, that favours destruction of hydrocarbon deposits, and that is conditioned by:

(a) sharp raising of big oil and gas-bearing territories (or their separate sectors) and diversion of the formed oil deposits to the zone of hypergenesis (or paleohypergenesis);
(b) development of the zones (or paleozones) of infiltration of water, containing additional oxygen, both laterally (essentially from the envelope of the basin) and vertically due to deep erosional incisions, and the other exogenic processes;
(c) extensive rupture tectonics, salt diapyrism, mud volcanism and formation of the other pathways helping hydrocarbons to go out of the trap, including the seepage of oil to the surface (current or ancient);
(d) sharp increase in metamorphism intensity and deformation of deposits, that previously were oil and gas bearing; intrusive magmatism and so on.

By intensity of concentration of natural bitumens, the oil and gas-bearing basins are ranged into the following tectonic types: (1) basins of marginal deeps (West-Canadian, West-Venezuelian, Leno–Anabarsky basins, and others); (2) the basins of the ancient platform deeps (Volgo–Urals, Tungussky, Timano–Pechorsky and others); (3) basins of intermountain depressions of epigeosyncline and epiplatform orogens (Fergansky, Sakhalino–Okhotsky, Raono–Kurinsky and others); (4) basins of continental margins: periocean and pericontinental (Lower Nigerian, Camerunian, Barents-Sea basins and others).

The first group of basins contains about 90% of the world geological resources of natural bitumens. The second group contains about 7–8%; 2–3% fall on the rest two groups.

The basic areas of concentration of natural bitumens are the following: (a) external, monoclinal edges of deeps (not complicated by elevations), adjoining to the crystalline shields and deeply eroded platform elevations (Type I); (b) eroded archs and paleoarchs; zones of jointing between interplatform depressions and elevations developed contrastingly in Mezo-Cainozoic and in the New period; large inversion structures (Type 2); (c) slopes of large eroded elevations at the edges of depressions (for the platform complexes); monoclinal edges of depressions (for orogenous complexes); dislocated and disturbed zones of depressions (Type 3); (d) monoclinal edges of depressions adjoining to the crystalline shields (Type 4) and others.

For the basins of certain types and their large structural elements specific groups of bitumen accumulations are typical. This factor was used upon prediction of the structure and composition of NB deposits in various oil–gas-bearing basins of the USSR (Fig. 1. The Map of bituminous basins of the USSR).

4. SPECIFIC CHARACTERISTICS OF GEOLOGICAL STRUCTURE OF TYPICAL NATURAL BITUMEN ACCUMULATIONS IN THE USSR

Characteristic features of geological structure of natural bitumen accumulations have been considered by an example of two basins (Volgo–Urals and Leno–Anabarsky) located in the Soviet Union.

In the Volgo–Urals basin numerous accumulations of bituminous rock are known from the old times. But systematic geological-exploration activities connected with their investigation began to be carried out only during the last decade. NBA, located in the southern part of the Tatar arch and Melekesskaya depression are studied more extensively. Here, more than 2000 wells are drilled for prospecting and exploration of natural bitumen accumulations. More than 300 areas are defined, where accumulations are concentrated in the Lower-Permian deposits. Among them about 30 accumulations are explored with different degree of detail.

Approximately $\frac{1}{3}$ of the geological resources of the Permian bitumens is concentrated in terrigenous reservoirs whereas $\frac{2}{3}$ of them are located in carbonate reservoirs. The most favourable conditions for producing Permian bitumens are associated with bitumen-saturated sand-aleurite rock occurring at the depth of up to 150 metres. Bitumen accumulations in most cases are confined to lithological traps characterized by the lense-like structure and high reservoir heterogeneity. Thickness of bitumen-saturated sand bodies reaches 25–40 metres, whereas the width ranges from 0.5–2.5 kilometres and the length reaches 3–5 kilometres.

Reservoir porosity ranges from 3–45%, whereas permeability varies from 0.001–1.2 mkm^2. Bitumen content ranges considerably (from 1–8%) reaching in individual areas 10% and more. More than 20% of bitumen resources are associated with reservoir rock of bitumen saturation higher than 5% (by weight). Bitumens are represented, mainly by viscous

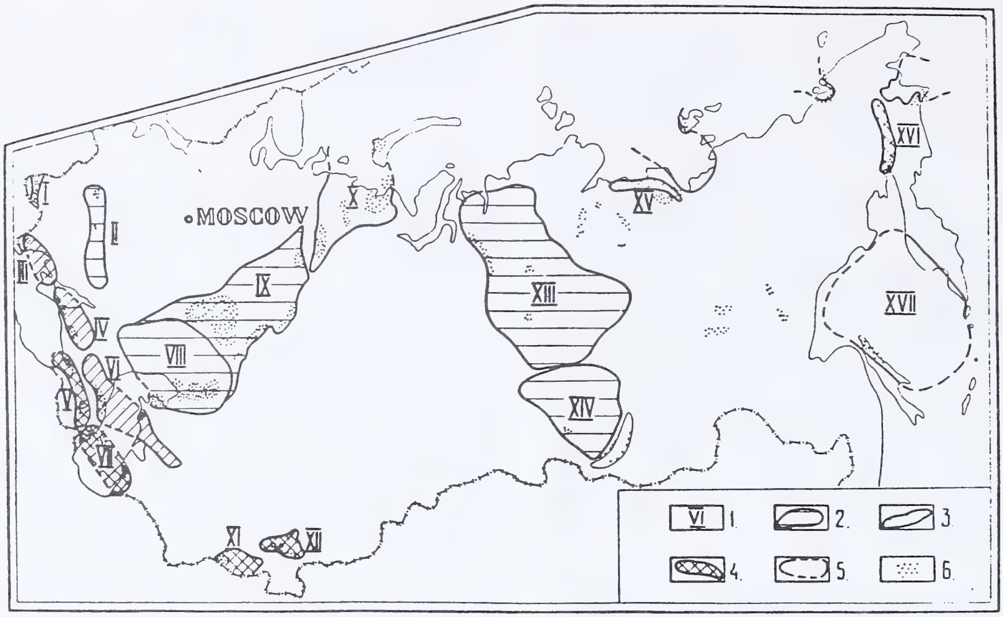

Fig. 1. The map of bituminous basins of the USSR. 1. Number of a basin; 2. Basins of the platform depressions; 3. Basins of the mountain deeps; 4. Basins of the intermountain depression; 5. Basins of a marginal part of continents; 6. Zones of the maximum bituminous accumulation. Basins: I. Pre-Carpathsky; II. Dnieprovsko–Donetsky; III. Severo–Chernomorsky (Northern Black Sea region); IV. Azovó–Kubansky; V. Riono–Kurinsky; VI. Sredne–Caspiysky (Middle Caspian Sea region); VII. Yuzhno–Caspiysky (Southern Caspian Sea region); VIII. Pre-Caspiysky (Pre-Caspian Sea region); IX. Volgo–Uralsky (Volga–Urals); X. Timano–Pechorsky (Timan–Pechora); XI. Afghano–Tajiksky; XII. Fergansky; XIII. Tungussky; XIV. Irkutsky; XV. Leno–Anabarsky; XVI. Penzhinsky; XVII. Sakhalino–Okhotsky (Sakhalin–Okhotsk).

malthas. They are characterized by high values of density (0.97–1.01 g/cu cm) and viscosity (2 to 10 Pa · s). They are found to be resinous and sulphurous (content of sulphur ranges from 3.5–4.7%). Hard bitumen (asphalts, asphaltites are of subordinate importance. Heavy oils and bitumens of the region under consideration are rich in vanadium, nickel and the other rare metals.

The specific feature of the structure of the majority of bitumen deposits is the uneven character of the surface of the water-bitumen contact, their inclination towards the direction of the regional flow of the Permian subsurface water. In a number of cases variation of absolute marks of the surface of the contact reaches 25–30 metres (Fig. 2. Gorskoye oilfield, Tataria. Geological cross-section). This is, probably, due to destruction of bitumen deposits by bottom water.

The peculiar characteristic of the structure of the bitumen deposits in Tataria is the presence in their section of numerous flooded layers of lower bitumen saturation, as compared with the other layers having the same capacitance-flow properties. Formation of such undersaturated layers should be assigned to the process of destruction of oil deposits, when in the hypergenesis zone together with biological destruction of hydrocarbons an important role played the processes of washing-out light fractions from oil (for the first turn from high-porous and high-permeable layers) by infiltration (seepage) and reservoir water.

The degree of saturation of such layers can be determined only by the value of volumetric bitumen-saturation (β_v), obtained from the core analysis and log data. When β_v data are not available, the intensity of undersaturation can be evaluated with the help of the values of bitumen saturation (by weight) (β_w), using $\beta_w = f(m, \beta_v)$ plots prepared for specific regions (Fig. 3. Relation between bitumen saturation by weight, volumetric bitumen saturation and porosity of terrigenous Permian rock for some oilfields in Tataria).

Regular increase in the number of the flooded layers within the cross-section of bitumen deposits is

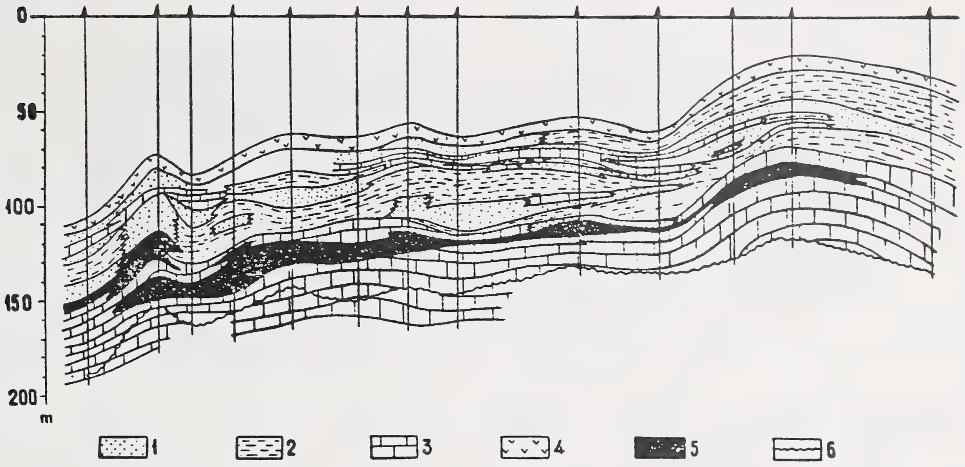

Fig. 2. The Gorskoye oilfield (Tataria). Geological cross-section. 1. sandstones; 2. aleurolites; 3. carbonate rocks; 4. gypsum; 5. bituminous rocks of Permian age; 6. unconformable surface.

observed towards the top of the Tatar arch (Fig. 4. The curves of distribution of bitumen saturation in various zones of the Tatar arch).

Investigation of the forms of bitumen distribution through porous space in the rock of the Lower Permian Tatarian deposits, conducted with the slides (microsections), showed their water-repellent (hydrophobic) nature. For such types of the reservoirs the presence of essential amount of free water is typical. This is confirmed by the results of sampling the bitumen wells. Application of the nuclear-magnetic resonance method showed that free water content in bitumen-bearing reservoirs varies from 15–50% depending on their lithological composition, type of cement and bitumen saturation. Connate water content rarely exceeds 10%.

Bitumen is characterized by various physico-chemical properties and various mobility ratios. According to the field log data, in the rock, for instance, only 20–30% of mobile bitumen is contained, whereas 50–70% of its volume is immobile. To recover this bitumen from the wells using tradi-

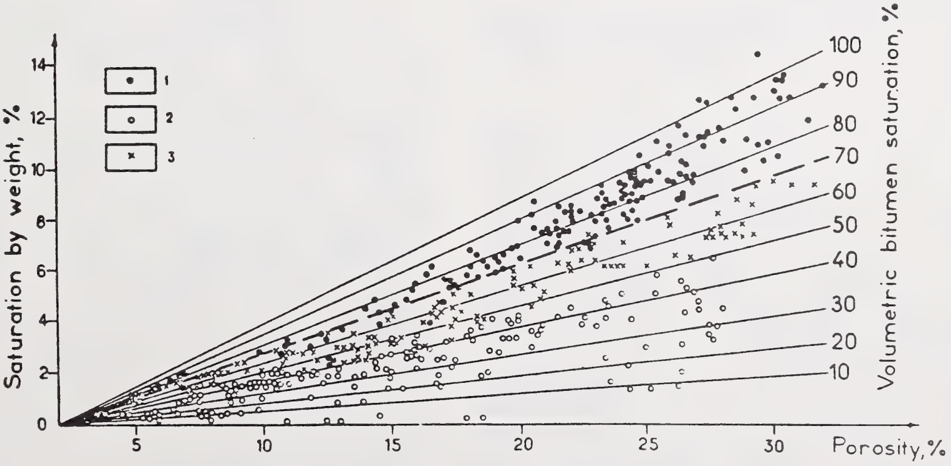

Fig. 3. Relation between bitumen saturation by weight, volumetric bitumen saturation and porosity of terrigenous permian rock for several oilfields of Tataria. Bitumen saturation: 1. Higher than 70%; 2. less than 50%; 3. 50–70%.

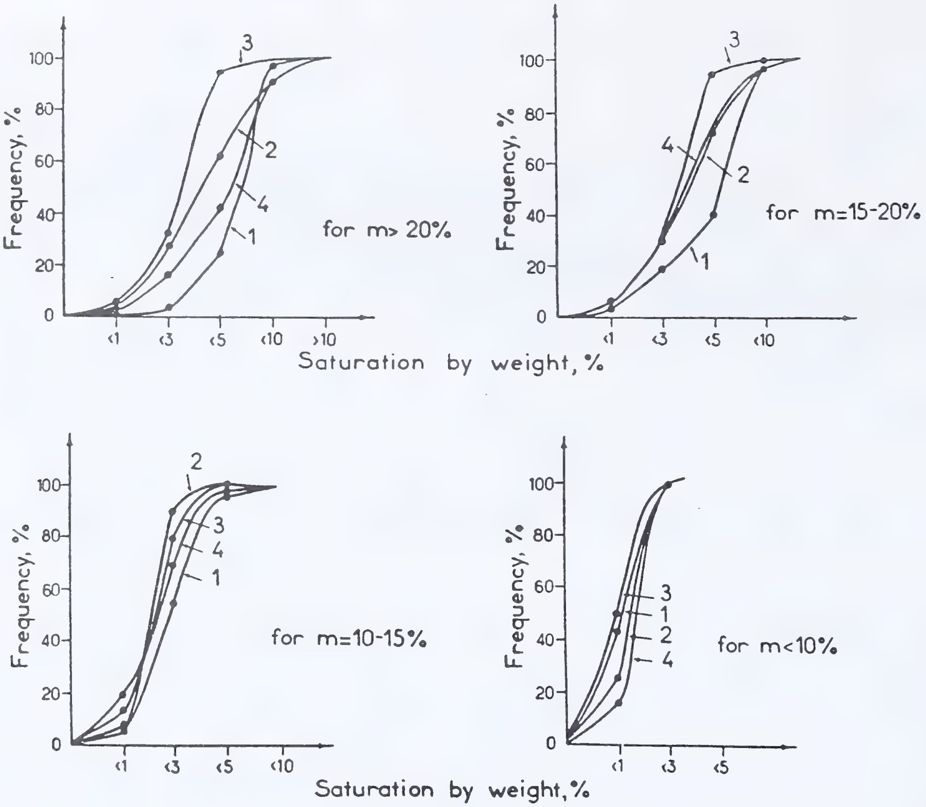

Fig. 4. The curves of distribution of bitumen saturation in various zones of the Tatar Arch. 1. The Sheshna-river basin; 2. Western slope of the Southern dome; 3. The arch of the Southern dome; 4. Southern-eastern slope of the Southern dome; m is porosity.

tional methods is impossible. For this purpose, application of reservoir enhancement methods (thermal methods, electrical heating, solvent injection and so on) is required.

In the Leno–Anabarsky basin, in particular, within the Oleneksky elevation bitumen-bearing rocks are represented in a wide stratigraphic range: from Pre-Cambrian to Cainozoic. They are represented by carbonate and terrigenous deposits characterized by essential variation of the degree of bitumen saturation, concentration and classes of bitumen. Location of bitumen accumulations is regulated, mainly, by structural and lithofacial factors.

The largest within the limits of the region under consideration is Olenekskoye NBA, that is associated with a gently sloping monocline deeping to the north at an angle of 1–2°. Dimension of the area of bitumen accumulation in strike is 120 kilometres, in dip-more than 40 kilometres.

The limits of the bitumen-bearing zone are, mainly, confined to the Permian deposits of 30–60 to 340 metres thickness, that transgressively overlap the Upper Cambrian dolomites (Fig. 5. Olenekskoye oilfield, East Siberia. Geological cross-section). Polimict sandstones of various graininess, characterized by oblique stratification, are considered to be reservoir rock in the cross-section of the Permian deposits. V. I. Ivanov has determined a quite definite relationship between reservoir fluid characteristics of these rocks and their granulometric and cement composition. Thus, porosity and permeability noticeably decrease from medium-grained to fine-grained sandstones (Fig. 6. Geologo-physical characteristics of bituminous rocks in the Olenekskoye oilfield). All the rocks, containing coalinite cement, are characterized by low porosity (less than 10%), permeability (less than 10^{-3} mkm^2) and bitumen saturation (less than 1% by weight).

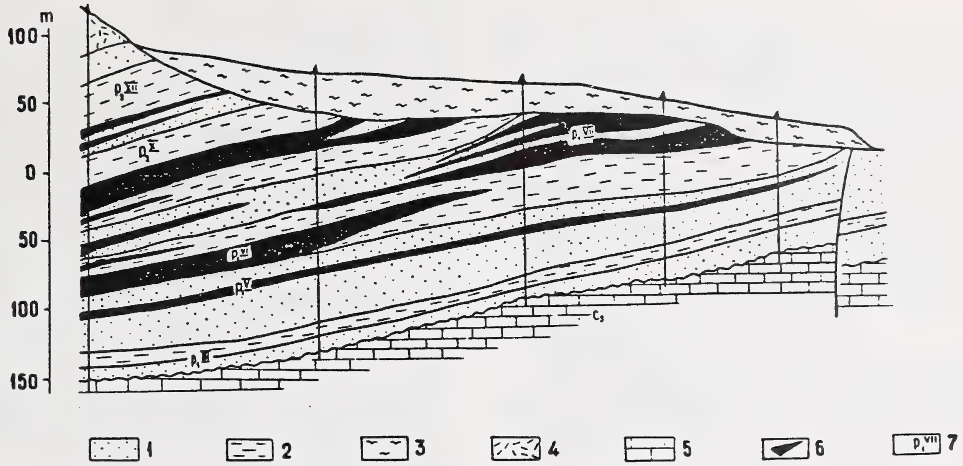

Fig. 5. The Olenekskoye oilfield (East Siberia). Geological Cross-section. 1. sandstones; 2. argilites; 3. Quaternary deposits; 4. turf sandstones; 5. carbonate rocks; 6. bituminous rocks; 7. paybeds of Permian age.

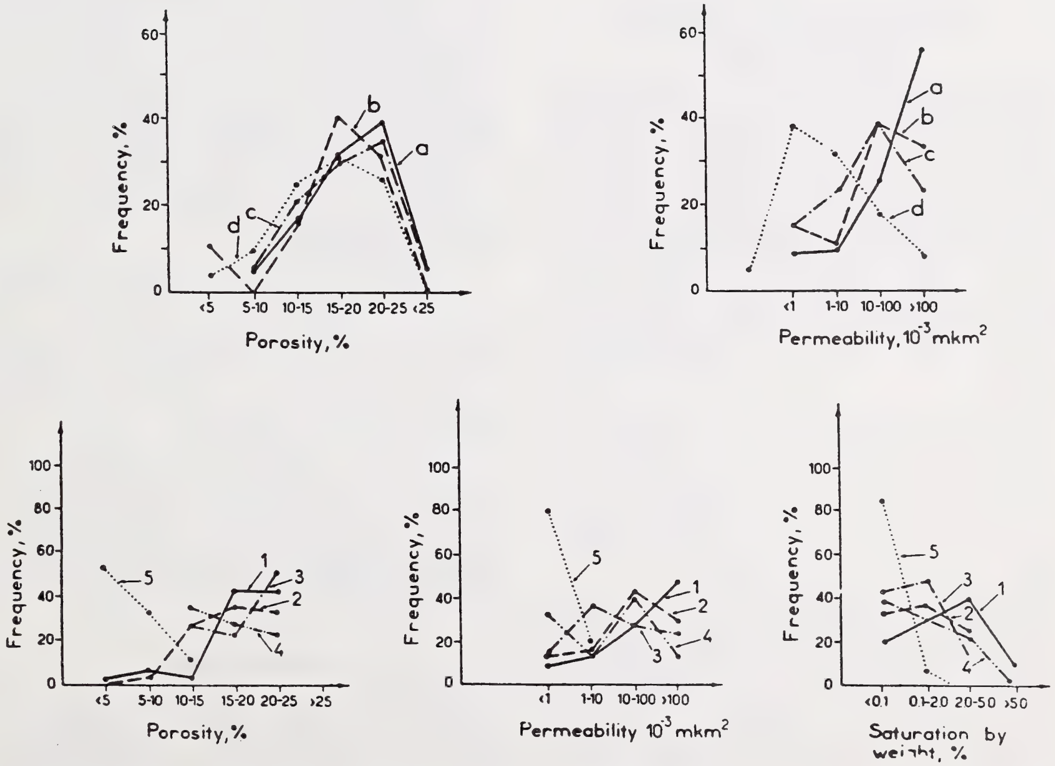

Fig. 6. Geologo-Physical characteristics of bituminous rock of the Olenekskoye oilfield. Sandstones: a. middle-grained; b. various-grained; c. fine grained; d. aleurites. Composition of cement: 1. caolinite; 2. caolinite-carbonate; 3. caolinite-hydromica; 4. hydromica; 5. carbonate.

Bitumen saturation within the Oleneksky NBA as a whole is not high. The highest bitumen saturation (5–10% by weight) is noticed in the areas composed by coarse-grained and medium-grained sandstones of high porosity (20–28%) and permeability (higher than 0.5 mkm^2).

Distribution of bitumen essentially depends on a structural factor; the highest bitumen saturation is observed in relatively elevated zones of the deposit.

Bitumens of the Oleneksky NBA are basically represented by mathas more seldom, by asphalts and asphaltites. The formation of accumulations of these bitumens is associated with hypergenous destruction of the Paleooleneksky oilfield. The Rossohinskoye and Siligir–Marhinskoye NBA (asphalts and asphaltites), where bitumen saturation is associated with the Lower Cambrian limestones and dolomites, are confined to the northern and southern slopes of the Anabarsky rock mass.

5. GEOLOGICAL AND ECONOMIC PROBLEMS OF PRODUCING NATURAL BITUMEN

In spite of the fact, that in the USSR numerous bitumen accumulations are found, their commercial production has only been carried out on a very small scale. The Shugurovskoye and Sadkinskoye asphaltic fields located in the Volga–Urals region are produced by the use of an open-pit process, whereas the Borislavskoye ozokerite field in West Ukraine is produced using the mining process. In three areas of Tataria the pilot-commercial tests for producing bitumen through the wells (*in situ* combustion, steam injection, electrical heating) are being conducted.

More wide commercial production of NB with application of various methods, was retarded by insufficient intensity of the study of the conditions of formation, mode of occurrence and spatial extension of NBA, as well as by absence of a scientifically-grounded evaluation of their resources.

During the last decade the interest to the solution of the problem of investigation and producing natural bitumen has increased. This is caused not only by the fact, that their resources can play an essential role in improvement of the fuel-energy balance of the total country in future but also with detection of capability of the diverse use of NB in various branches of the national economy.

A new approach to bitumen raw material, as well as the first results of investigation of specific characteristics of the bitumen deposit, geological structure, and the methods to be applied for production has allowed more optimistic evaluation of the perspectives of development of NBA detected in the European part of the country (firstly, in the Volga–Urals region).

The preliminary design and experimental data of producing NB with application of different methods in the USSR showed, that the use of natural resources of bitumens is characterized by high unit costs. However, the costs for NB production are comparable with the predicted costs for production of conventional oil. The main economic indicators for the open-pit and mining production of NB and heavy oil are quite similar. The process of producing NB through the wells, in spite of the lower recovery ratio, in comparison with the production by mining, is more perspective (taking into account the depth of NBA occurrence and the value of NB in the market).

The economic evaluation of NB production will be more complete, if one will evaluate NB value as a fuel used instead of 'energy' coal produced in the basins of the European part of the USSR. The comparative analysis showed, that the mining and open-pit methods of producing bitumen from deposits with even unfavourable geological characteristics, are more profitable than production of coal, in general, and production of coal in the regions, located not far from the centre of the country, especially (1.7–2.5 times more profitable).

The multicomponent composition of NB causes the necessity of its more extensive processing, as compared with processing of conventional oil. On average, processing of NB (calculated both per unit of raw material and per marketable products) requires 2–2.5 times higher expenses in comparison with processing of traditional oil.

Elaboration of the effective methods for producing NB applicably to geological and physical conditions of the specific fields and organization of the diverse use of bituminous rock allows the essential cut of the terms of producing NBA discovered in the European part of the USSR and East Siberia.

CONCLUSIONS

The evolution-genetic approach to investigate the processes of naphtido-genesis has permitted evaluation of the important factors of oil transformation, followed by formation of natural bitumen accumulations. By commonality of genetic characteristics and mode of occurrence three groups of accumulations are defined: hypergenous, phase-migrational and thermalmethamorphic.

Accumulations of natural bitumen are formed within the sedimentary oil–gas-bearing basins, mainly, at the last stages of their evolution.

The cutting of costs of natural bitumen production can be connected with their complex use, taking into account a high content of rare elements, sulphur and the other useful components of the mineral part of the bitumen-containing rock in them.

Development of new effective methods of producing natural bitumen accumulations is the most important problem of the accelerated production of this valuable mineral.

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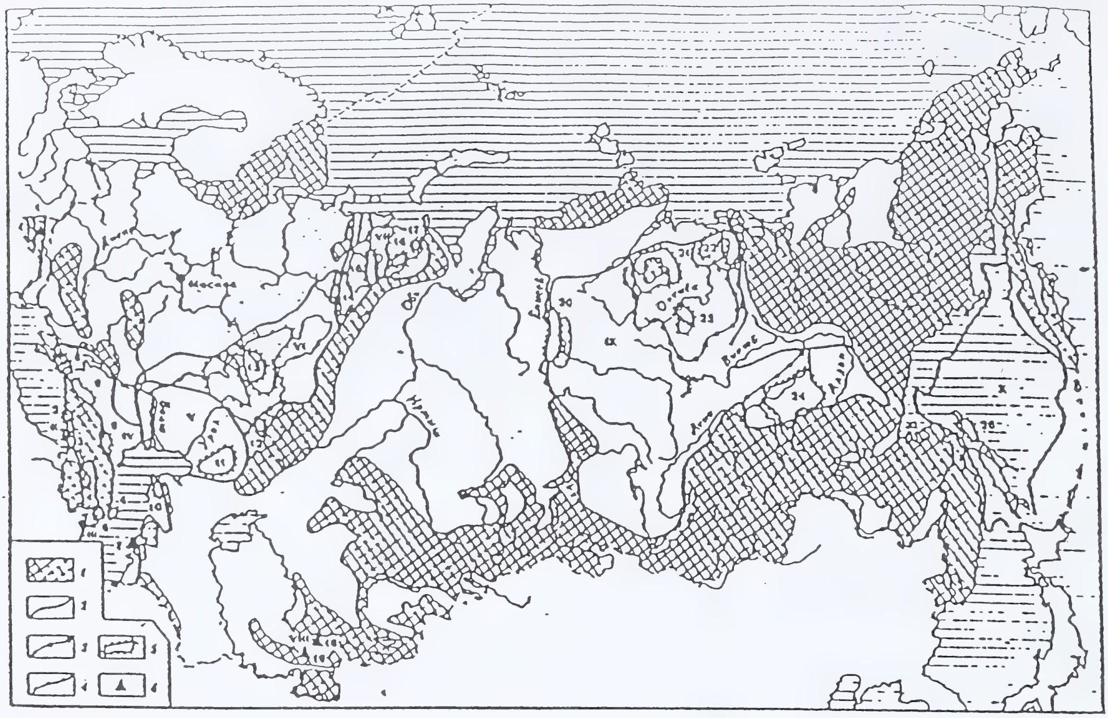

Regionalization of natural bitumen deposits in the USSR.

Legend: 1—shields and fold regions
2—boundaries of bitumen-bearing provinces
3—major tectonic structures
4—lesser tectonic structures
5—accumulation zone of asphalt-type bitumens
6—accumulation of ozocerite (a solid paraffin hydrocarbon)

Regionalization:
I—Carpathian province (1—Borislav-Pokut'ye zone)
II—Black Sea province (2—Gagra; 3—West Rioni)
III—South Caspian province (4—Kura-Iori; 5—Shemakha-Gobustan; 6—Apsheron)
✓IV—North Caucasus-Mangyshlak province (7—Chekken; 8—Kerch'-Taman; 9—south margin of Caucasus foreland; 10—Beke-Bashkuduk)
V—North Caspian province (11—central Emba)
VI—Volga-Urals province
12—west margin of Belaya depression
✓13—Sok-Sheshma zone; eastern margin of Melekess depression; west and southwest slopes and apex of South Tatar arch)
VII—Timan-Pechora province
14—Ukhta zone
15—Pechora zone
16—Khoseda yu zone
17—Talota zone
VIII—Fergana province (18—North Fergana; 19—South Fergana)
IX—Lena-Tunguska province
20—Turukhansk zone
21—Medvezh'ye-Anabar zone
22—Olenek zone
23—Siligir-Markha zone
24—Lena-Amga zone
X—Okhotsk-Sakhalin province (25—Sakhalin zone).

Source: A. A. Aksenov, P. S. Zhabreva, N. V. Kolesnikova. *Zony bitumonakopleniya SSSR* [Bitumen Accumulation Zones of the USSR]. Moscow: Nauka, 1986, p. 22-23.

SOVIET UNION: FACTS AND FIGURES

OFFICIAL NAME:	Union of Soviet Socialist Republics (U.S.S.R.)	
POPULATION:	277,930,000 (July '85)	
	Average annual growth rate: 1.0% Population density: 12.3 per sq. km.	
ETHNIC GROUPS:	52% Russian 16% Ukrainian 32% among over 100 other ethnic groups.	
MAJOR CITIES: (1985)	Moscow (the capital)	8,642,000
	Leningrad	4,867,000
	Kiev	2,448,000
	Tashkent	2,030,000
	Baku	1,693,000
	Kharkov	1,554,000
	Minsk	1,472,000
	Gorky	1,399,000
	Novosibirsk	1,393,000
	Sverdlovsk	1,300,000
	Kuybyshev	1,257,000
	Tbilisi	1,158,000
	Dnepropetrovsk	1,153,000
	Yerevan	1,133,000
	Odessa	1,126,000
	Omsk	1,108,000
	Chelyabinsk	1,096,000
	Donetsk	1,073,000
	Alma-Ata	1,068,000
	Ufa	1,064,000
	Perm	1,056,000
	Kazan	1,047,000
AREA:	22,402,200 sq. km. 35.5% forests 16.8% pasture and hay 10.2% cultivated 37.5% other	
LANGUAGE:	Russian (official); more than 200 languages and dialects (at least 18 with more than 1 million speakers); 75% Slavic group, 8% other Indo-European, 12% Altaic, 3% Uralian, 2% Caucasian.	
LITERACY RATE:	99.8%	

REPUBLICS

REPUBLICS (JAN. 1985)		AREA ('000 sq km)	POPULATION ('000s)	CAPITAL	POP. OF CAP. ('000s)
Armenian	SSR	29.8	3,317	Yerevan	1,133
Azerbaijanian	SSR	86.6	6,614	Baku	1,693
Byelorussian	SSR	207.6	9,942	Minsk	1,472
Estonian	SSR	45.1	1,530	Tallinn	464.000
Georgian	SSR	69.7	5,201	Tbilisi	1,158
Kazakh	SSR	2,717.3	15,842	Alma-Ata	1,068
Kirghiz	SSR	198.5	3,967	Frunze	604.000
Latvian	SSR	63.7	2,604	Riga	883.000
Lithuanian	SSR	65.2	3,570	Vilnius	544.000
Moldavian	SSR	33.7	4,111	Kishiniev	624.000
Russian	SFSR	17,075.4	143,090	Moscow	8,642
Tadzhik	SSR	143.1	4,499	Dushanbe	552.000
Turkmen	SSR	488.1	3,189	Ashkhabad	356.000
Ukrainian	SSR	603.7	50,840	Kiev	2,448
Uzbek	SSR	447.4	17,974	Tashkent	2,030

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